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Charles F. Eckart

Charles F. Eckart died in California on June 20, 1934. The part that he took in the development of scientific agriculture in Hawaii was an important one, and he may be looked upon as one of the pioneer workers in the application of science to sugar production in these Islands.

A chemist by profession, he came here first in 1895 in the employ of the Paauhau Sugar Plantation Company. It was in that year that the Experiment Station of the Hawaiian Sugar Planters' Association was started under the direction of Walter Maxwell. A year later Mr. Eckart became associated with Dr. Maxwell in the work of the Station. When Dr. Maxwell left the Islands for Australia in 1900 he was succeeded for a brief time by R. E. Blouin, and when Mr. Blouin returned to Louisiana in 1901, Mr. Eckart became director of the Station.

With the development of new branches of work in 1904-1905 he participated in the direction of the enlarged activities (as director of the Division of Agriculture and Chemistry) with Dr. R. C. L. Perkins (director of the Division of Entomology) and Dr. N. A. Cobb (director of the Division of Pathology and Plant Physiology). In 1909 when the three divisions were combined as a single institution, Mr. Eckart became director of the reorganized station, and continued in that office until June, 1913, when he resigned to become manager of the Olaa Sugar Company, Ltd. In 1920 he became a director of that company and participated in its management in a consulting capacity for several years. He moved to California in 1926.

During the early years of his connection with the Experiment Station his work included fundamental studies of Hawaiian soils, and the problems of tolerance of sugar cane to saline irrigation waters. The important question of cane varieties later received his attention, and following the work of Soltwedel in Java, and that of Harrison and Bovell in Barbados, he and his associates undertook the propagation of seedling varieties of sugar cane in Hawaii.

In 1905 a group of 5,000 seedlings was germinated and as these attained maturity in 1907 thirteen were marked by Mr. Eckart as particularly promising

canes. One of these, given the number "H-109," was a few years later adopted and spread rapidly at Ewa by the late George F. Renton, and afterwards by all the irrigated plantations of Hawaii, attaining finally an area of over 100,000 acres, and contributing greatly to the large crops of sugar produced in Hawaii in recent years.

At Olaa, Mr. Eckart developed some interesting and novel agricultural practices. He was the first to make practical application of a chemical herbicide between the rows of a cultivated crop, and he was the inventor of a system of paper mulching, used originally in cane fields, and since widely employed in pineapple culture.

Mr. Eckart was born in Marysville, California, June 18, 1875. He was a graduate of the University of California, and also held a post-graduate degree from that institution. He will be remembered and honored for the constructive work that he did for the betterment of agriculture.

In This Issue:

The Regional Variety Stations in the Seedling Selection Program:

The harvesting results from the Field Test 2 plantings on the regional stations are summarized. The different parentage groups and types which have shown to best advantage in each station are discussed; and the procedure followed in choosing seedlings in these tests for plantation trial is outlined.

Introduced Tropical American Toad:

This beneficial amphibian has found Hawaiian conditions suitable as a new habitat and is now definitely established and multiplying rapidly. Its life history and food habits, as observed in Hawaii, are given together with a discussion of its general behavior, methods of rearing, growth and local distribution to date.

Water and Cane Ripening:

This paper reports the results of a preliminary study to determine the effect of withholding water upon the formation and storage of sugar in cane. It represents an attack upon the important problem of the effect of water upon cane ripening, made from the physiological point of view.

The results show that the manufacture of sugar occurs in cane at the wilting point, but at a reduced rate. Whether the increase in the formation of sugar which occurs in the plants receiving an adequate amount of water is enough to offset the loss due to their increased growth, remains to be determined in the next experiment.

The Basic Reasons for Phosphate Fixation:

In previous articles phosphate fixation has been discussed in a general way, and also with respect to the variation in the fixing powers of different soils. Phosphate fixation is here treated from the standpoint of determining what causes soils to fix

phosphates, and what actually takes place in a soil when phosphates are fixed and held by it.

The phenomenon of fixation is not alone one of simple chemical precipitation, or merely that of adsorption (the property by which one substance can attract and hold another substance as bone char adsorbs the coloring matter of a sugar solution). The study indicates that *absorption* plays a prominent part, that is, the property by which two substances become intermingled in a state known as the "solid solution". We have examples in metallic alloys.

The phosphate-fixation property of a soil relates to its colloidal structure. A colloidal state may exist by reason of great fineness of division of a substance, but colloids may also take the form and complex structure of a gel. It is within the gel-like structure of certain soils that phosphates are thought to be fixed by a process of absorption and held in a state difficultly available to plants.

Fixation of phosphates may be thought of as due to a combination of simple chemical precipitation, adsorption and absorption.

For Better Field Experiments with Fertilizers:

A series of plans for fertilization and arrangements of treatments is offered as examples that may be used by plantation agriculturists who desire to install high-grade field experiments concerned with fertilizer problems and related issues.

A Required Standard for "Grade A" Experiments:

At a meeting of plantation men held at Hilo early in 1931, it was the consensus of opinion that continued emphasis should be placed on well-planned, well-replicated, carefully executed field experiments, the results of which could be considered reliable; and it was proposed that such experiments meeting this standard would be officially termed "Grade A" experiments.

Following several years of study and consideration of the many factors which make for a high standard of excellence in field experiments, we have adopted a set of minimum standards for those experiments which the Experiment Station is to recognize as "Grade A."

Potash Occurring in Irrigation Water in Relation to Plant Fertilization:

This paper describes in detail a study made upon fields in two locations on Central Maui, where the irrigation used consists of pump water which carries comparatively high concentrations of potash.

Researches are described bearing upon the functions of this potash as a plant nutrient for sugar cane. Data are set forth and discussions ensue which lead to the conclusion that the potash in the irrigation water has actually contributed to the fertilization of cane, and in one case is apparently responsible for a luxury consumption of the nutrient by the crop. References are made to other studies bearing upon the subject. Comparisons are also included of analytical procedures used in the course of the investigation.

The Regional Variety Stations in the Seedling Selection Program

By C. G. Lennox

In 1930 the first plans were laid for the establishment of seedling testing stations in locations which would be typical of the different large areas of land under sugar cane cultivation. Some of the fields at the Waipio Substation were being used in preliminary selection work with the new seedlings, and while it was recognized that the growth conditions there were suitable for testing for irrigated conditions, in general, they were not typical of many of the cane areas in the Islands. A deliberate attempt to select representative locations resulted in the establishment, in 1930, of testing fields at Hilo Sugar Company as being typical of the so-called Caledonia belt on the Hilo Coast, and in the middle irrigated "eye spot" belt at Lihue Plantation Company, Ltd., on Kauai. The following year sites were chosen as representative of the middle belt on the Hamakua Coast and of the mauka lands on the Hilo Coast. These areas were augmented the following year by one in the middle belt of the Kohala District and one at the highest elevation at which cane is grown in the Hamakua District.

The purpose of the regional station plan is twofold. First, it relieves the plantations of the expensive and difficult task of testing many relatively untried seedlings. Second, it strengthens the whole seedling testing program by offering an opportunity to observe the behavior of the new canes under a wide variety of conditions as well as offering a plan for their careful testing in each district for a period of 3 to 6 years before they are released to the plantations.

During the harvesting season of 1934 a full cycle of testing has been completed at all the regional stations except Kohala. The seedlings which have completed this cycle have passed through the following stages:

(1) Field Trial 1 in which only eight feet of line is planted to each seedling and the final selection is made at the end of one year. Selection is based primarily upon agricultural qualities and apparent weight of cane as compared with the check variety. A Brix reading will eliminate the canes exceptionally low in sucrose content.

(2) Field Trial 2 in which a plot of three lines 15 feet long is planted to each seedling and the final selection is made at the end of 20 to 24 months. Check plots of the standard variety are planted adjoining each seedling. Selection is based upon the yield of sugar per acre as compared with the standard variety and the appearance of the cane on the ground at harvest.

The few seedlings which are chosen for plantation distribution are those which have outyielded the check by a good margin and the general records of which for sucrose content, disease resistance and agricultural qualities are all satisfactory.

It will be of interest to examine the results of this first completed cycle of testing at each regional station.

A Field Trial 2 planting in which a plot of three 15-foot lines are planted to each seedling and the final selection is made at the end of 20 to 24 months. The distribution charts which follow in this article show the tons-sugar-per-acre gain or loss of the seedlings in these tests over the standard cane at each variety station.

Waipio Variety Station

The preliminary testing of seedlings was started at Waipio two years before those at the other regional stations so information is therefore available on the ratoons of Field Trial 2. The distribution chart shown in Fig. 1 gives a general idea of how the seedlings under trial compare with H 109 on the whole. The population represents a wide assortment of parentages ranging from Uba seedlings through the medium-stalked type produced by P.O.J. 2364 to the large-stalked seedlings of Yellow Caledonia. The majority are of the series propagated in 1928.

The plant crop was 22 to 24 months old at harvest and shows a total of 95 seedlings outyielding H 109. The canes in this group represented a fair cross-section of all the parentages in the population although the P.O.J. 2364 group predominated. The first ratoons were harvested as a short crop. The value of P.O.J. 2364 blood for short cropping purposes is clearly demonstrated here for it is found dominating the group of high yielders.

Fig. 2 shows the distribution of the tons-sugar-per-acre gain and loss over H 109 of a population of 605 seedlings harvested for the first time in 1934. The relative high standard of this new group, as witnessed by the fact that more than half the number outyielded H 109, might be attributed to the following:

(1) A more rigid selection from the F.T. 1 planting due to a larger number of seedlings from which to select.

(2) A wider range of parentages to work with due to the fact that newly

introduced breeding canes had been employed in making many of these crosses. (Seedlings of the 1927, 1928, 1929, 1930, and 1931 series were represented in this population.)

(3) A knowledge from past experience as to which types and parentages succeed under these conditions.

The question naturally arises as to how such an unwieldy number of seedlings can be reduced to a number of convenient size to work with on plantations. This is accomplished by submitting each individual to a critical examination which in brief is as follows:

(a) Seedlings which show a gain of from one to two tons of sugar per acre only over the check are eliminated unless their other records are well above the average. This eliminates those which have possibly made their gain through chance experimental errors.

(b) A careful examination of the cut cane reveals the individuals with excessive dead cane, borer or rat damage, and trashiness. These qualities which comprise "condition of cane at harvest" play a large part in reducing the number.

(c) The greatest elimination comes when the records of each individual are referred to and a general idea is obtained on its performance in a number of other plantings. These data tell us whether the high yields obtained in the experiment were to be expected or are possibly "fluke" gains and may not happen again. The factors looked for when examining the records are: average juice quality, ratooning ability, shading-in characteristics, tasseling tendencies, ability to *lala,* and tolerance of the diseases found in the various districts.

The process of weighing all the qualities of one cane against those of another gradually reduces the number to a comparatively small group. Within the group remaining there are all degrees of confidence in the seedlings represented. Those in which we have the greatest confidence are the ones on which the greatest number of favorable observations from different plantings are available.

The seedlings which have not quite measured up to a standard high enough to include in the group for plantation distribution are not discarded but are given additional trials in Field Trial 2.

In following the procedure of elimination described we find it is possible to reduce the 350 seedlings which outyielded H 109 at harvest, as illustrated in Fig. 2, to a group of only 30. Even this number is not suitable in its entirety for all irrigated conditions because some are too susceptible to eye spot disease. It is interesting to note that the wide range of parentages, represented in the original population of 605 seedlings, is not found so distributed among the 30 leaders; for here 17 are hybrids of P.O.J. 2364, 3 of Yellow Caledonia, 3 of P.O.J. 2878, and 7 of miscellaneous parents.

Hilo Variety Station

It has often been pointed out that Yellow Caledonia is a difficult variety to replace for the conditions existing on the Hilo Coast. This is well substantiated by the fact that relatively few seedlings outyielded Yellow Caledonia at the Hilo Station as compared with the larger proportion which did so at the Waipio, Kauai, and Hamakua stations.

It will be noted in Fig. 3 that 43 seedlings bettered Yellow Caledonia in tons sugar per acre by a wide range of gains. A study of this group reveals that more than one-third of this number were P.O.J. 2364 hybrids, with the Uba x H 456 seedlings next in prominence. After the whole number had passed through the scrutinizing process we find 8 remaining as suitable for distribution. P.O.J. 2364 blood still dominates this group to nearly a complete exclusion of all others.

The selection of seedlings for the conditions found on mauka lands of the Hilo Coast is conducted in a field located at an elevation of approximately 950 feet. The standard variety used is P.O.J. 36, which has replaced D 1135 in these parts within recent years. Fig. 4 shows the distribution of the T.S.P.A. gains or losses of the 51 seedlings in the "Field Trial 2" tests harvested at this location in 1934. A total of 15 outyielded P.O.J. 36. They are all seedlings of Uba x H 456 except Co. 281 and Co. 290. The factor of "susceptibility to leaf scald disease" plays a large part in reducing the number suitable for plantation distribution to only five.

Hamakua Variety Station

A rather wide range of parentages are adaptable to the conditions found in the middle belt of the Hamakua District. In the population of 43 (see Fig. 5) which was harvested this year as 21-month old cane, we find the 32 seedlings which outyielded the standard (P.O.J. 36) in sugar to be from crosses of Uba x H 456, P.O.J. 2725 and P.O.J. 2364 x Yellow Caledonia seedlings, and a few from miscellaneous small-stalked parents. The largest proportion, however, are of the first-named parentage, which indeed distinguished itself by having all of its seedlings in the total number tested outyield P.O.J. 36.

After the process of examining all qualities of each seedling was complete a total of 11 remained as material good enough for plantation distribution. Uba x H 456 dominates this select group, with all the P.O.J. 2725 and P.O.J. 2364 seedlings eliminated, excepting 28-1234. In addition to these, three seedlings of miscellaneous parents remain.

Kauai Variety Station

The element of eye spot resistance in a new seedling is of primary importance in the selection for F.T. 2 testing at the Kauai Variety Station. The result is that many canes which may be outstanding in agricultural qualities must be eliminated because of susceptibility to this serious disease. A total of 104 eye spot-resistant seedlings were harvested as 21-month old cane, and as Fig. 6 shows, there were 33 which showed gains in sugar over P.O.J. 36. This number was reduced to 9 when eliminations were made for small-stalk canes, poor juice records and other features. A rather wide range of parentages is represented in these few.

Summary

In the foregoing discussion an attempt has been made to point out the different parentage groups as well as different types which have shown to their best advantage under the climatic and cultural conditions existing at each station. The annual accumulation of information of this nature adds to the knowledge of which

type and which general parentage groups will give the most satisfactory results at each place. They also aid in determining the broad lines of breeding policy to be followed. The choice of the few outstanding individuals for distribution to plantations is strengthened, (1) by virtue of a trial conducted under the general field conditions for which they are intended, and (2) by the added surety given by observations from different plantings.

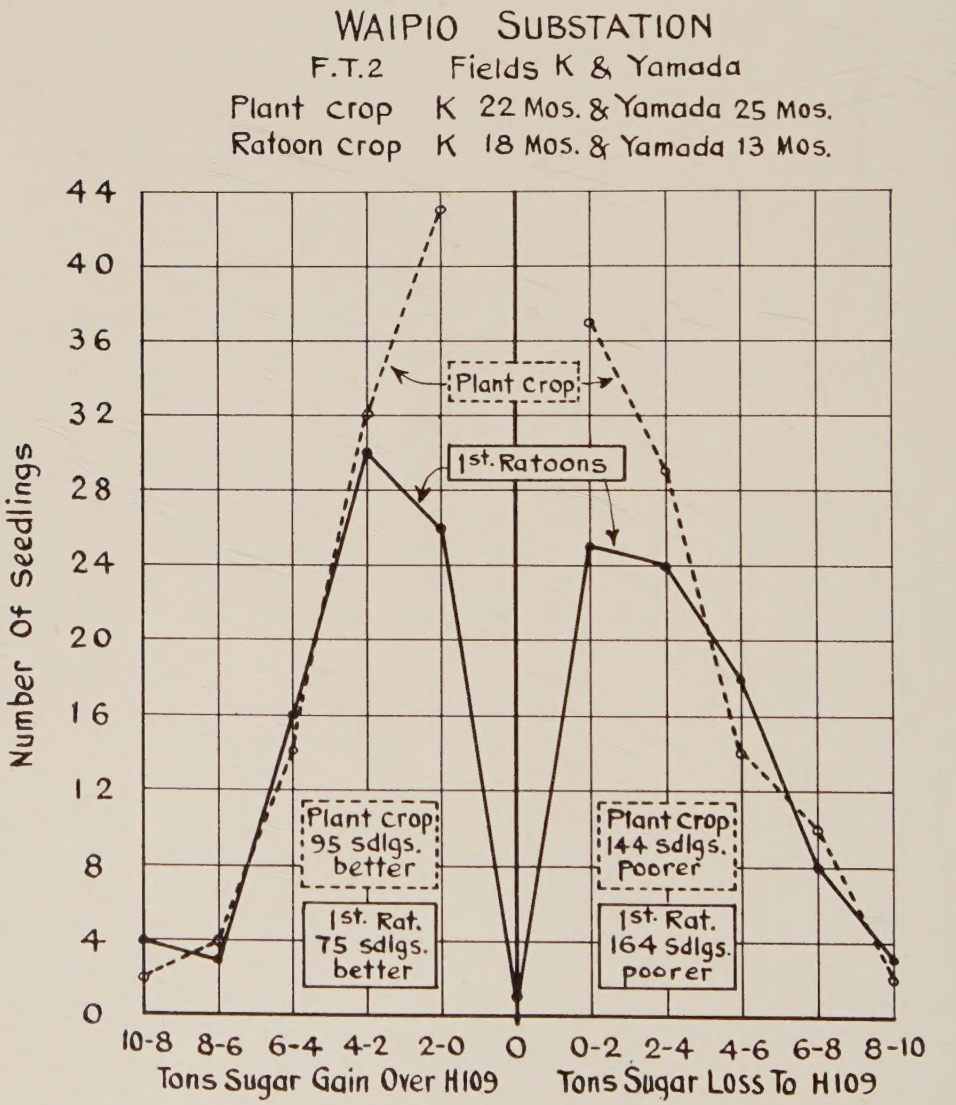


Fig. 1. Seedlings of P.O.J. 2364 are among the highest yielding canes in both the plant and ratoon crops represented above.

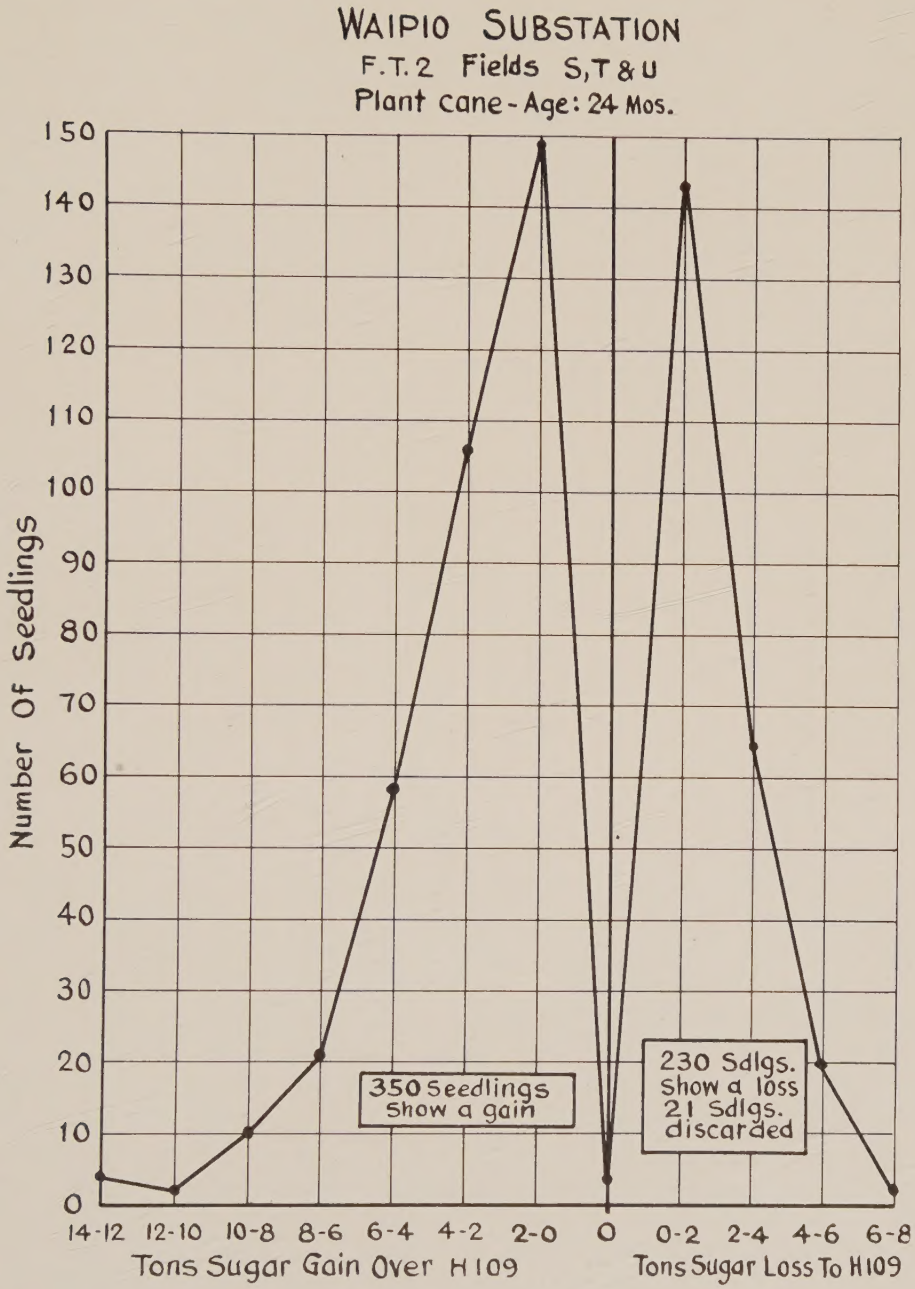


Fig. 2. When the records of the 350 seedlings which outyielded H 109 are carefully scrutinized it is found possible to reduce this number to a group of 30 seedlings suitable for recommending to plantations for trial under H 109 conditions.

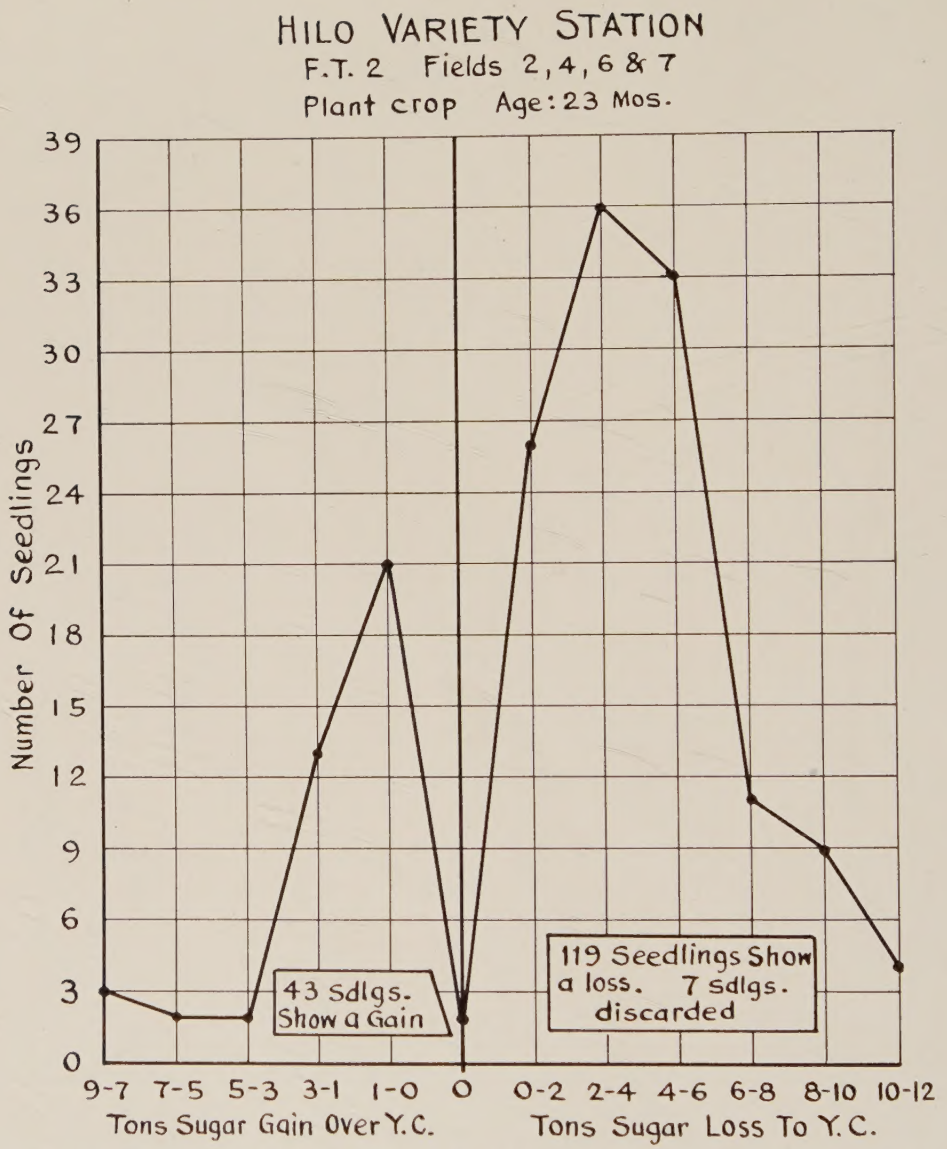


Fig. 3. The strong position held by Yellow Caledonia on the Hilo Coast is well illustrated by the relatively small percentage of seedlings which bettered it.

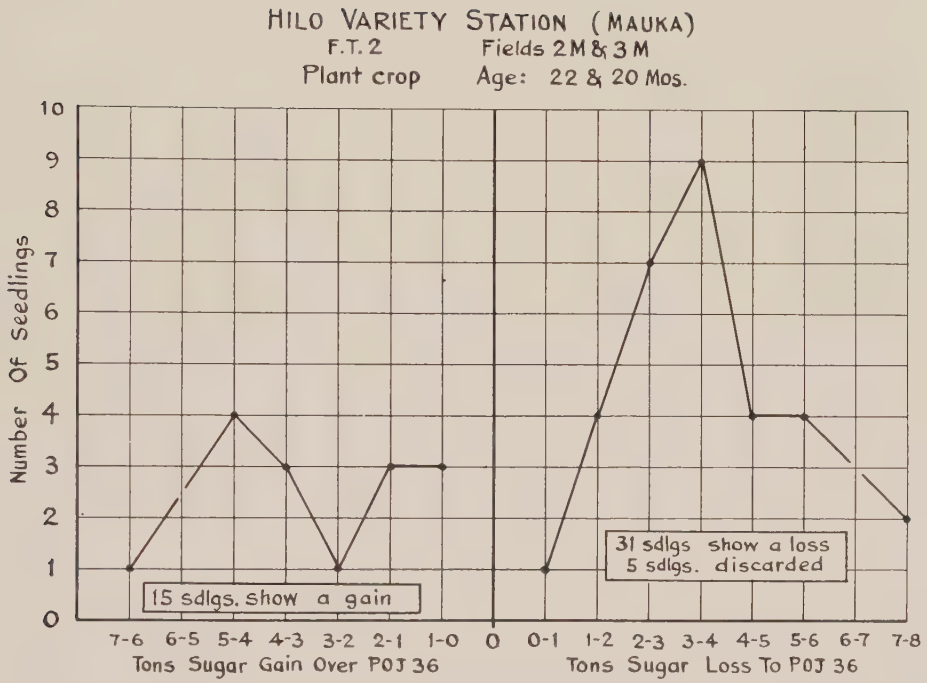


Fig. 4. Co. 290, Co. 281 and three seedlings of Uba x H 456 are the few in this population which are considered worthy of further trial under these conditions.

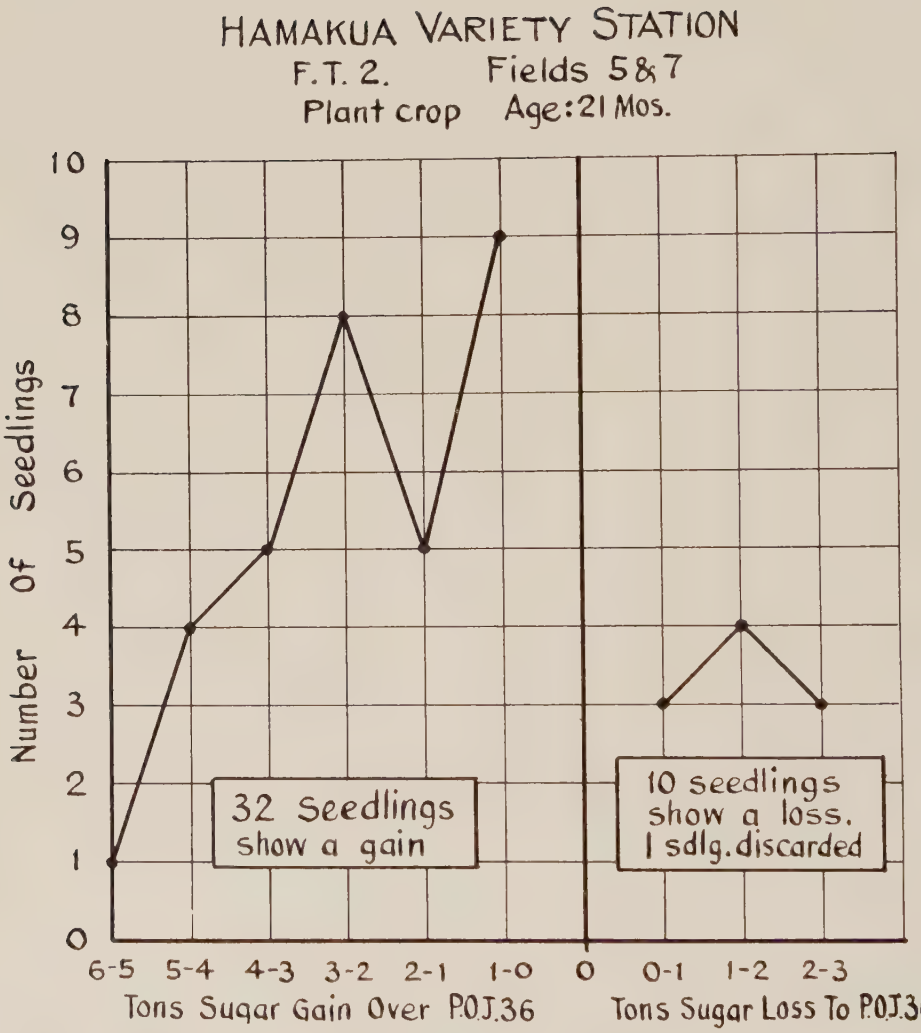


Fig. 5. The distribution curve shown above would indicate that P.O.J. 36 is a weak competitor against nearly all the new seedlings in the test. The factors of economy of weed control and rapidity of ratooning play a large part in reducing the number which are suitable for trial on plantations from 32 to 11.

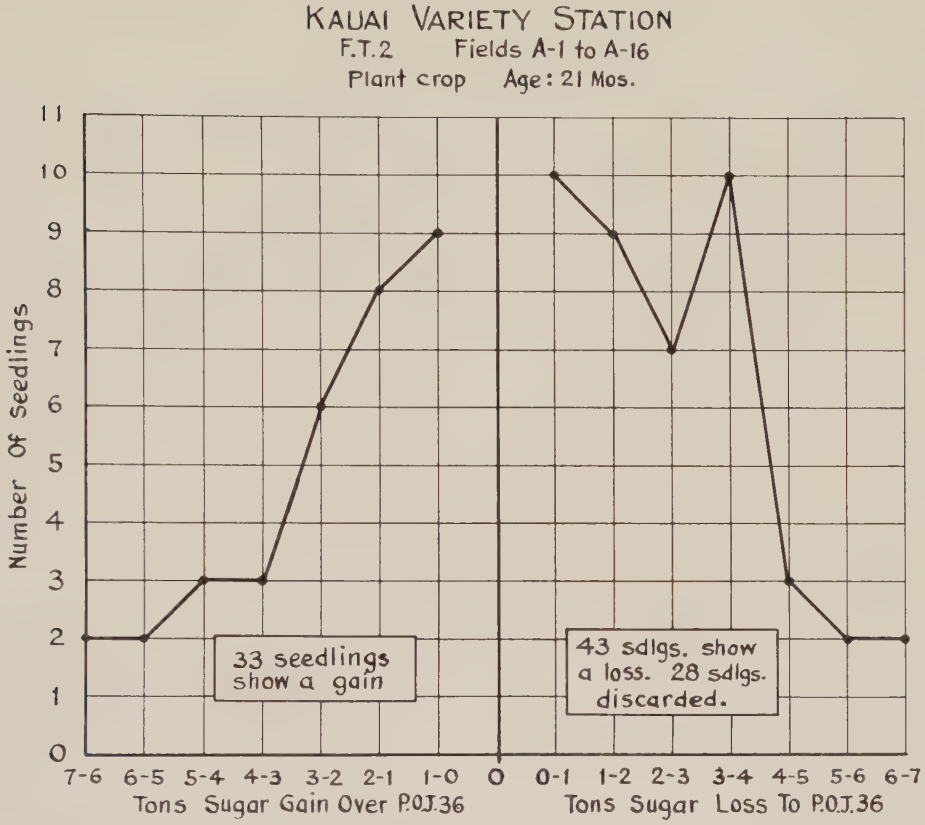


Fig. 6. All the seedlings in the population are commercially resistant to eye spot disease. After an examination of the records 9 can be chosen as worth further trial.

Local Investigations on the Introduced Tropical American Toad *Bufo Marinus*

By C. E. Pemberton

The introduced giant tropical American Toad *Bufo marinus* (Linné) has now added one more item to its interesting history, for it is definitely established in the Pacific Region for the first time and is multiplying rapidly on Oahu. This, the largest of the true toads, was first described and figured by A. Seba in 1734. The specimen examined by Seba was part of a collection bought for 15,000 Dutch guilders by "Peter the Great" of Russia in 1716 and deposited in St. Petersburg. This collection became part of the St. Petersburg Academy of Sciences, established by Catherine I, December 21, 1725.* Linnaeus named the toad *Rana marina* in 1758. With its establishment in the Hawaiian Islands, importation to other parts of the Pacific will naturally follow. Already a small consignment has been taken from Honolulu to the Philippine Islands.

In a little over two years the 148 toads which were introduced into Hawaii from Puerto Rico, have increased their number to many thousands. This rapid development has resulted entirely from the original field liberation of 80 in a taro patch bordering a rice field at Waipio, Oahu, and 68 in some swampy land in the Manoa Arboretum at the head of Manoa Valley, Honolulu. These liberations were made during April, 1932. All were good-sized toads. Young toads were first seen at Waipio, August 31, 1932, and in Manoa Valley, March 7, 1933. Only a few were found but this gave proof that eggs had been laid and that the species would probably become established. By May, 1933, quite a number of half-grown Hawaiian-born individuals were seen in upper Manoa Valley, and in August of the same year many young toads were found in a rice field at Waipio. It was also comparatively easy to find, in the same locality, some that were of fairly good size. It seemed quite probable that Hawaiian-born toads of this species had started egg-laying by September, 1933, for many young toads began appearing in several parts of Waipio and even in the Waipio reservoir, which is well-removed from the spot where the original liberation was made. The sudden appearance of young toads in fair quantity in upper Manoa Valley further substantiated this belief.

The toad has spread slowly down Manoa Valley from the point of original liberation. It now abundantly occupies the taro patches of the valley and is frequently seen in the residential gardens, especially on the western side.

Commencing in May, 1933, a few distributions were made from Manoa Valley and Waipio to other localities on Oahu. During the latter half of 1933, the species rapidly gained headway and distributions were increased. By the end of the year, 947 had been moved to many places on Oahu and some had been sent to other islands. During the first half of 1934, thousands were obtainable at Waipio and

* Mexican Tailless Amphibians in The United States National Museum. By Remington Kellogg. Bulletin 160, United States National Museum, Smithsonian Institution, Washington, D. C., 1932, pp. 53-57.

Fig. 1. *Bufo marinus.* Adult 16½ months old. Insert. The same 3 days old *all natural size.* The young toads weighed approximately 1/10 of a gram each, whereas the adult tipped the scales at 491 grams. This increase in weight, by nearly five thousand times in 16½ months has resulted from the consumption of from 1500 to 2000 insects.

distributions have been made to every plantation in the Territory. At the present writing (July 23, 1934), a total of 103,517 has been distributed. Most of these toads have been placed within Anomala-infested portions of Oahu Sugar Company, Ltd., where this insect is the most abundant. Fair numbers have also been liberated in Anomala-occupied fields of Honolulu Plantation Company and Ewa Plantation Company. Almost all of the distributed toads came from Waipio.

Most of the toads so far distributed have been young individuals. From present evidence, it seems certain that they are not sexually mature until about a year old. The large number of immature toads distributed to date cannot be expected to begin multiplying until the summer of 1935. The saturation point for this toad in Hawaii will not be reached for several years; but within one or two years from the present date it will probably be sufficiently numerous to be familiar to almost every resident in the Territory, if the increase to date from the few introduced individuals can be accepted as an index.

The large distribution accomplished during the past few months, has been made possible through the enterprise of F. C. Denison at the Waipio Substation of the Experiment Station and certain members of the staff under his direction, notably L. M. Shigeura. Toad eggs are collected from the rice field adjoining the Waipio Substation and held in large pans of water until they hatch. The tadpoles are then placed in large pans of water set into the ground in pens several yards square in which grass and weeds are growing. The pens are partially shaded by overhanging branches of mango trees. Running water circulates continuously through the pans. Though tadpoles normally feed upon green algae and other minute aquatic plant life, Mr. Denison found, after experiment, that poi, boiled rice, cooked Cream of Wheat and Carnation Flakes were greedily eaten by the tadpoles and that they developed to the toad stage quicker if given such artificial food in place of the green algae. By such a method of feeding he determined that the Bufo tadpoles became fully developed and changed into young toads in about 25 days. With normal food, such as they obtain under natural conditions, we find that the tadpole stage occupies about 30 days. Eggs hatch within a few days after being deposited. Some kept under observation during May, 1933, began hatching 2 days and 20 hours after being laid. The newly hatched tadpoles are 1/5 of an inch long and absolutely black. When full grown they are less than an inch long. A pair of hind legs is plainly discernible when the tadpole is about half grown and a few days before it matures to a toad the front pair of legs also appears.

As soon as the tadpole stage is ended, the aquatic life of the immature Bufo is abruptly given up and the young toad, hardly more than ¼ of an inch long, climbs ashore and begins foraging for ants and minute insect life among the weeds and grass close to the water from whence it has emerged. They prefer to remain where the ground is cool and moist and will readily plunge back into the water if disturbed. Quantities of ants are placed daily in the cages at Waipio to supply the first food for the young toads as they change from tadpoles in the pans of water and come ashore. Within a few days they are ready for distribution and will stand shipment very well through the mails to the other islands, if packed loosely in moist excelsior in any container which will not be crushed. The cages can be kept heavily stocked with young toads through the collection of only a few Bufo egg-masses per month. The eggs are laid in curling rows or strings several

feet in length. They are jet black and imbedded in a mass of gelatin-like substance. By counting the number of eggs within a given length of a part of one egg-mass, it was estimated that the total number of eggs per mass amounted to at least 10,000.

Fig. 2. Toad hatchery at Waipio.

It is not known how many times a year a toad may deposit eggs, but egg-masses have been found in the field at Waipio almost every month of the year. During 1933, our first year of study, no eggs were found during the summer months; however, during July, 1934, after the toads had become very numerous in the rice field at Waipio, eggs were found and it is quite probable that they will appear from now on during every month of the year.

As already stated, the newly developed toad is hardly over a quarter of an inch long. Some have been measured which averaged about 2/5 of an inch from the front of the head to the tip of the stubby tail. This tail is soon absorbed. After a week or more of feeding on ants and other very small insects, the toad gains rapidly in strength and agility and may attempt an insect barely small enough to pass into its mouth and down its throat. Growth is rapid and they seem exceptionally able to find and capture all the insect food they require. Toads in our cages that were three months old, varied from 2½ to 3 inches in length and would even swallow mature Chinese grasshoppers *Oxya chinensis;* but only after considerable effort and by assistance with their hands or front feet. Twenty-five toads, which have been reared in a cage and fed all the insects they required, varied in size from 3½ to 4⅝ inches in length at the end of 6 months. F. X. Williams placed two young toads in a cage during February, 1933, to observe their growth and habits. These were 2/5 and 3/4 of an inch in length, respectively, at that time. They have been fed about all they could eat up to the present date (July 23, 1934). One is now over 6 inches in length and more than 4 inches

in width at the widest part. In order to attain such a growth in 16½ months, an individual toad undoubtedly consumes from 1500 to 2000 insects of various sorts.

From our local observations it is apparent that *Bufo marinus* will eat any insect that comes within its reach, large or small, providing the toad has grown sufficiently to enable the victim to pass down its throat. We have fed them grasshoppers, armyworms, beetles, earthworms, scorpions, wasps, moths, bees, house lizards or geckos, ants, many sorts of caterpillars, snails in the shell, cockroaches and sow bugs or slaters; all of which were taken with little discrimination. The geckos are usually too quick and secretive to be caught without our assistance. If these tender reptiles are held before a toad, they are quickly grasped and swallowed, apparently to the great satisfaction of Bufo. A toad about 4 inches in length was given a male carpenter bee *Xylocopa varipuncta,* with the wings trimmed to prevent its escape; this was swallowed without hesitation. A female bee of the same species was later given to the same toad and was also immediately snapped up and passed down the insatiable Bufo gullet with ease. This large black carpenter bee, so commonly found boring in redwood fence posts and other wood structures in Hawaii, possesses an exceedingly powerful sting which is used effectively at the slightest provocation. Undoubtedly the bee will continue stinging for a few moments, at least, after passing suddenly into the interior of a toad. It is astonishing that a toad will, without hesitation, gulp down a bee possessing such a formidable weapon of defense and apparently suffer no discomfort. After swallowing such a fiery creature as a carpenter bee, Bufo was observed to execute a few abdominal motions suggestive of the Hawaiian "hula dance". Spiders are always eaten with relish if they come within reach of the lightning-like flash of the toad's tongue. Dr. Williams found that freshly decapitated centipedes, which are still able to crawl, are eaten apparently without fear of injury; but the many legs of large centipedes are usually able to cling over the mouth or head of the toad so tightly that the process of swallowing such a long object is often accomplished only after much laborious gulping and pushing and pawing with the front feet in a very human but "inelegant" manner, according to Dr. Williams' notes. A half grown toad was given a very large and uninjured centipede, measuring at least 6 inches in length. This was almost immediately grasped in the mouth and several attempts were made to swallow it. In this case, however, the powerful muscles and smooth skin of the centipede, assisted by its many, strong, claw-tipped legs, enabled it to successfully escape. Good-sized toads will easily capture and swallow centipedes four inches in length.

Toads consume scorpions without difficulty. The largest scorpions we have been able to find in Honolulu are readily swallowed by toads less than half grown.

Usually when given more insects than can be consumed within a short period, Bufo will cease feeding but only after its body has become visibly engorged.

Toads will feed at any time of the day or night, but are most active after sunset. They are known to visit certain spots where food is obtainable at regular intervals, once such spots are located. In Puerto Rico, shrubs on which certain defoliating beetles accumulate in the evening, are known to be regularly visited at night by this toad for the evening feast, after which it returns to some safe retreat to spend the day. The possession of such an instinct or memory usually results beneficially to man, but in one case, at least, the reverse was true. Mr.

Denison recently discovered that toads congregated in the evening at two of his bee hives, which were low on the ground, and ate the bees as they crawled back and forth at the entrances. This difficulty was overcome by raising the hives two or more feet above ground. Apiaries could be easily protected in a similar manner, or by constructing a low wire fence entirely around the establishment.

It is not probable that toads will eat their own young. If such a cannibalistic habit occurs it must be uncommon. During May, 1934, fifteen young toads, slightly over ¼ inch in length, were placed in a cage with 25 large toads. These young ones have not been eaten after two months of close confinement with their larger brethren.

Dr. Williams kept two toads under observation for 10 months and recorded in his notes some very interesting facts relative to their feeding and other habits. These observations started during February, 1933, and extended to the end of the year. Toads moult the skin frequently during growth. Dr. Williams' observations on the process of moulting, as taken from his notes, follow:

> After feeding Bufo No. 2, I noticed that it soon lost interest in further food and, at a little provocation, flattened down with a hiss. It was occupying a small flower pot. At about 9:18 p. m. it could be seen that it was shedding its skin. The skin had evidently split on the back from posterior forwards, sliding or rolling down the sides. The new, exposed skin was very moist, warty and paler than the old coat. I noted the skin slip down and off one of the large parotid glands and seemingly over the face. The toad, which seemed to be in considerable discomfort, would squirm, contracting the belly and pushing under it with the hind limbs, lifting itself up and also pushing forward with the hands on each side of the mouth, where a dark strip of skin could be seen leading into the mouth. Every now and then it would open and shut its mouth, sometimes closing the eyes and giving the impression of yawning, but really swallowing the dark rolled up skin. The tongue, of course, was not extruded. The moulting, I think, occupied less than 20 minutes. A few minutes thereafter the Bufo resumed its appetite, swallowing the two large gecko lizards presented.

Dr. Williams succeeded in inducing one of the confined toads to eat a half-grown frog tadpole, when held before it, but when given a young frog *(Rana rugosa)* about 1½ inches long, an attempt was made to swallow it, but it evidently proved highly distasteful to the toad, for it was immediately disgorged and refused thereafter. He hand fed these toads for many months until one could be held on the hand, when it would snap up the lizards, grasshoppers, etc., presented. Dr. Williams states in his notes that:

> When ill-disposed, as during the daytime, they will swell up and hiss, when disturbed. When in the open they may leap off; when in a flower pot or corner, the head is often lowered, giving it a frowning or baleful look and the inflated toad may, apart from hissing, further show its displeasure by quite powerfully butting at an offending hand.

This toad can certainly see a small moving object some feet away from its body. Dr. Williams observed that the toads in his cage could distinctly see moving objects 3 feet distant.

It is remarkable that toads can swallow stinging wasps and bees without much apparent discomfort, since the effort to sting must continue for a few moments, at least, after the insect has been swallowed. It is even more remarkable that so muscular and venomous a creature as a centipede will also be taken as food. On the subject of centipedes and toads, we quote further from Dr. Williams' notes:

I customarily give the toads decapitated Scolopendra centipedes. This evening (September 25, 1933) Bufo No. 2 promptly grabbed one, head end foremost. It had great difficulty swallowing it, for the posterior legs of the centipede made very fast to the toad's foreleg so that it could not be disengaged. Bufo became quite stirred up, hopped about and headed plump into the flower pot, striving mainly to pull loose, not however letting go the fore end of the centipede. Finally I helped it loose and the centipede was swallowed. Bufo No. 1 was then given a large decapitated centipede, which it took. This was followed by tremendous activity on the part of the toad. It plunged about and used its arms in an essay to swallow the centipede, which had secured a grip with its hind portion on the toad's breast. Finally the toad swallowed all but the last pair of legs of the centipede, which hooked over the toad's mouth, but at last the centipede disappeared wholly inside.

The evening song of the male toad can now be readily heard on quiet evenings in taro patches, rice fields and reservoirs, where the species is well established. The sound can be easily distinguished from the harsh, rasping croak of the common frogs which are found in the same localities. The song can perhaps be best described as a rapid succession of deep, flute-like notes. By some, it has been described as resembling the sound of a distant diesel engine; others have compared it with the muffled sound of a motorcycle in the distance. The females utter clucking, complaining sounds sometimes when disturbed, but are not considered as finished and ardent vocalists as the males.

Attempts to breed this toad in confinement have been unsuccessful. Two cages at the Experiment Station contain toads from 13 to 16 months old, but, to date, no eggs have been laid in the water to which they have constant access. These toads have eaten thousands of insects during the year or more of confinement, have grown rapidly and appear perfectly normal in every respect. Investigators of toads in other parts of the world have also found that confined toads are usually sterile, or at least do not multiply.

Toads will wander far from the points where originally liberated. They do not necessarily require reservoirs, streams, ponds or swampy places after they have once passed through the tadpole stage and gone ashore. Their food is apparently all taken on land. We have not seen them feed while in water, excepting when snapping at insects at the edge of the water. For multiplication, however, the toad requires water for the deposition of the eggs and the development of the tadpoles.

There have been a few records kept on the length of life of toads kept in confinement in other countries. From these records it is evident that a toad will live for many years. We have seen one authentic published account of a European toad *Bufo vulgaris,* which was kept in a box and provided with food and water for 12 years. At the end of this period the toad remained unchanged and normal. We can conclude that in Hawaii the death rate, as compared with the birth rate, will be very low until many more years have elapsed.

Water and Cane Ripening

By Constance E. Hartt

This paper reports a preliminary study of the formation and translocation of sugar in cane plants deprived of water, compared with plants supplied with water. Among the many important questions to be answered by research of this nature, the following may be mentioned: Does photosynthesis (manufacture of sugar) continue in a leaf of a cane plant in the wilting condition of ripening off? What is the effect of withholding water from the plant upon translocation of sugar from the leaves to the stems? Does the sugar content in a cane stick actually increase due to the checking of growth during ripening, or is the improvement of the juices due merely to a decreased dilution with water? In short, is the sugar planter justified in withholding water approximately three months before harvest or not? The data here reported are the results of a single experiment only and as such serve merely to introduce the subject. No attempt should be made to draw final conclusions as yet.

Methods

The plants used in this experiment were of the variety D 1135 and were obtained from R. J. Borden. They were twelve months of age. The plants, which had been grown for another purpose, had not received uniform treatment; to some had been given lime, others molasses, or other soil amendments. The plants receiving different treatments were equally distributed in the four series of the present experiment. The pots of plants, which had been outside, were transferred to the greenhouse. They were then subjected to a series of preliminary studies by H. A. Wadsworth, who collaborated in this experiment. The treatment consisted of withholding water from all the plants and making daily growth measurements to determine when the water content of the soil reached the wilting point. As shown by Wadsworth (31) at the wilting point cane ceases to elongate, which results in a flattening of the growth curves. All of the plants used in this experiment were subjected to these preliminary tests, thus all of the plants had been at the wilting point several times before the experiment had commenced. At the time of the experiment half of the plants were receiving a plentiful supply of water, but previous to that time water had been withheld and elongation had ceased temporarily. This point must be considered in evaluating the results of this experiment, as it is recognized that the control plants were not normal. However, at the time of the experiment the control plants were receiving water and were growing, whereas the experimental plants were not receiving water and had ceased to elongate.

All of the plants were put in the dark Saturday morning, June 2, 1934. The lecture hall of the Experiment Station was used for this purpose, having been rendered absolutely dark under the direction of H. L. Lyon and R. E. Doty. Half of the plants (including some supplied with water and some deprived of water) were returned to the greenhouse at 9:30 p. m. Sunday. These plants received light beginning about 6 a. m. the following day. The plants which remained in

the dark were sampled at 8 a. m. Monday, having been in the dark about 45 hours. Those which were returned to the light were sampled at 1 p. m. the same day, having received moderate sunlight for about seven hours. Thus there were four groups of plants, herein designated dark wet, dark dry, light wet, and light dry.

Sampling was conducted as follows: All of the sticks were cut at the point of attachment of the lowest living leaf sheath. Counting the leaf with the highest visible dewlap as No. 1, leaves 1, 2, and 3 were taken from each of eight or ten sticks in each series. The blades were separated from the sheaths, wiped, and ground (midribs included) with a Russwin Food Cutter, and were sampled immediately. The sheaths of the same leaves were ground and sampled similarly. The stems, which included green leaf millable cane and non-millable stem, were cut and ground and sampled. No determinations could be made with the dry-leaf cane, which Mr. Borden needed for his own experiment.

The ground material was thoroughly mixed. Duplicate samples were placed in weighed aluminum boxes and weighed immediately for moisture determinations. After the addition of 1 cc. of hot 95 per cent alcohol, these boxes were placed in a vacuum oven at 90° C. and dried to constant weight. Duplicate samples were weighed and plunged immediately into boiling 95 per cent alcohol, in flasks containing one gram of $CaCO_3$, for neutralization of acids. These samples were stored in the dark until analyzed. Sugars were extracted from the samples with successive treatments with hot 50 per cent alcohol followed by ether and 95 per cent alcohol. Determinations of total and reducing sugars were made on the extracts, using the Munson and Walker (22) method and the Bertrand (2) titration. Citric acid was used for the inversion of sucrose. The residue after extraction was oven dried, powdered, and thoroughly mixed. Samples of the dried powder were used for the determination of polysaccharides by the method of hydrolysis with HCl (1). Other samples were used for the determination of starch by the Taka-diastase method of Shriner (28).

Results

Moisture percentages are given in Table I, which shows that the plants supplied with water had higher percentages of water in the blades, sheaths, and stems than

TABLE I

Moisture Percentages in Cane Supplied With or Deprived of Water

Series	Blades	Sheaths	Green-Leaf Cane
Dark dry	67.89 ± 0.171	79.63 ± 0.088	84.36 ± 0.071
Dark wet	70.72 ± 0.248	85.21 ± 0.081	88.52 ± 0.043
Light dry	66.64 ± 0.014	76.30 ± 0.052	84.16 ± 0.014
Light wet	69.57 ± 0.162	84.20 ± 0.055	87.83 ± 0.088

the plants deprived of water. The plants harvested in the light contained smaller percentages of moisture than those taken in the dark, indicating a decrease in moisture percentage during the day, which has already been reported in another experiment (15). Of the three organs studied, the blades were the driest and the sheaths were intermediate in moisture content.

Because of the differences in moisture percentage shown in Table I, the data for sugars and polysaccharides are not expressed on the wet-weight basis. Two methods of expression are used, the usual moisture-free basis and the residual dry-weight basis. Because of the fluctuations in carbohydrates at various times of the day, the second method is desirable, as mentioned by Denny (9). The residual dry weight equals the dry weight from which are subtracted both the total sugars and polysaccharides. It will be noted that when calculated on the residual dry-weight basis the probable errors are greater than on the moisture-free basis. This is probably because the duplicate results for polysaccharides did not agree as closely as the other determinations. However, most of the results show significant differences. Differences are greater on the residual dry-weight basis than on the moisture-free basis, and do not always show the same trend. Where there is a difference in trends indicated by the two bases of calculation, it is felt that the results calculated on the residual dry-weight basis are the more reliable, as explained by Denny. This is because it is mainly the carbohydrates that are undergoing change in amount, thus the residual matter after subtracting the carbohydrates represents a relatively stable and constant fraction, and calculations on the basis of this unchanging residue should give a true measure of the relative change in two different samples, as explained by Denny. The results are expressed on the moisture-free basis for purposes of comparison with other data but the discussion will be based upon the residual dry-weight method of calculation.

The results of the determinations of reducing sugars, sucrose, polysaccharides, and starch are presented in Table II.

If the percentages in the plants taken in the dark are subtracted from the percentages in those taken in the light, an estimate of the increase or decrease during exposure to light is obtained. This has been done and the results are given in Table III. The trends on exposure to light are also shown graphically in Figs. 1 and 2, the former showing the results on the moisture-free basis, the latter on the residual dry-weight basis.

Reducing sugars in the blades show a real increase in the plants deprived of water but not in the others. When calculated on the residual dry-weight basis this difference is more conspicuous than on the dry-weight basis. Therefore the reducing sugars tended to increase in the blades of the plants deprived of water but not in those supplied with water, during exposure to light. This could be explained as follows: greater photosynthesis in the dry blades, slower translocation in the dry blades, or greater use of sugar in growth in the wet blades. The second two possibilities are the most reasonable.

Reducing sugars in the sheaths decreased more in the plants receiving water than in the plants deprived of water when the results are calculated on the residual dry-weight basis, but the reverse on the moisture-free basis. The results on the residual dry-weight basis indicate greater growth and/or greater translocation in the plants supplied with water.

Reducing sugars in the stems show significant differences on the residual dry-weight basis but not on the moisture-free basis. The stems of the plants deprived of water increased in reducing sugars but the stems of the controls decreased.

This could be explained by greater growth of the latter or by translocation of reducing sugars into the lower part of the stick.

Sucrose increased in the blades of both series, a greater increase occurring in the controls than in the blades of the plants deprived of water, on both bases of calculation. This could be explained by greater photosynthesis or greater sucrose synthesis in the blades of the controls, or poorer translocation of sucrose from the blades of the controls, or translocation of sucrose from the stems into the blades of the controls. The second suggestion is not probable inasmuch as water is the medium in which translocation occurs. The last suggestion might be true if the permeability of cell membranes increases during drying, in which case adding water might easily wash sucrose up into the leaves. This, however, should have taken place at night as well as by day, but there is no evidence of that occurring since the blades of the plants supplied with water became so low in sucrose during the night.

Therefore, the best explanation of the sucrose percentages in the blades is better synthesis of sucrose (or photosynthesis) in the blades of the plants supplied with water. Sucrose in the sheaths and stems shows the same trends on both bases of calculation, an increase in the plants deprived of water and a decrease in the controls.

Polysaccharides increased in the blades during exposure to light, the increase being slightly greater in the plants deprived of water than in the controls, on both bases of calculation. In the sheaths and stems there was a decrease in polysaccharides, a greater decrease in the plants supplied with water than in those lacking water.

The percentages of starch were small and showed little variation. Significant differences were not obtained in the blades, and only small differences in the sheaths. The results calculated on the residual dry-weight basis show that in the stems there was an increase in starch in the plants deprived of water, but in the stems of the controls, starch decreased during exposure to light.

The percentages of starch were subtracted from the percentages of polysaccharides. Table III shows that the polysaccharides other than starch occur in cane in considerable amounts, and fluctuate during the day.

Total sugars were recalculated as glucose and added to polysaccharides to obtain an idea of the total reserve carbohydrate material. Table III shows that the total reserve carbohydrate material increased more in the blades of the plants deprived of water than in the controls, when calculated on the residual dry-weight basis. In the sheaths there was a decrease in both series, the decrease being greater in the plants supplied with water. In the stems there was a considerable increase in the total reserve carbohydrate material in the plants deprived of water, but a decrease in the controls.

TABLE II

Carbohydrate Percentage in Cane Supplied with or Deprived of Water

Series	Reducing Sugars		Sucrose		Polysaccharides		Starch	
	m.f.*	res.*	m.f.	res.	m.f.	res.	m.f.	res.
Blades:								
Dark dry	1.592 ±0.008	1.926	2.437 ±0.066	3.147	14.15	17.628	1.173 ±0.041	1.543
Dark wet	1.092 ±0.023	1.280 ±0.028	1.663 ±0.051	1.950 ±0.061	11.92 ±0.000	13.975 ±0.012	1.278 ±0.019	1.498 ±0.672
Light dry	1.657 ±0.0005	2.224 ±0.040	3.083 ±0.109	4.148 ±0.218	20.63 ±1.209	27.819 ±2.113	1.068 ±0.058	1.435 ±0.047
Light wet	1.068 ±0.003	1.380 ±0.008	3.432 ±0.013	4.440 ±0.005	18.12 ±0.214	23.427 ±0.339	1.226 ±0.033	1.584 ±0.047
Sheaths:								
Dark dry	6.997 ±0.026	10.130 ±0.029	7.865 ±0.181	11.386 ±0.257	16.06 ±0.233	23.252 ±0.346	1.900 ±0.004	2.751 ±0.005
Dark wet	10.795 ±0.004	18.609 ±0.414	5.687 ±0.009	9.802 ±0.207	24.88 ±1.032	43.070 ±2.716	1.795 ±0.021	3.091 ±0.031
Light dry	3.861 ±0.154	5.273 ±0.138	9.659 ±0.526	13.275 ±0.904	13.37 ±0.643	18.363 ±1.135	1.803 ±0.008	2.470 ±0.045
Light wet	8.192 ±0.002	11.765 ±0.011	5.058 ±0.197	7.271 ±0.276	17.12 ±0.286	24.592 ±0.435	1.990 ±0.039	2.830 ±0.045
Green-leaf Cane:								
Dark dry	14.642 ±0.185	31.474 ±0.028	17.217 ±0.638	37.119 ±1.813	21.62 ±0.095	46.524 ±0.753	5.963 ±0.079	13.51 ±0.064
Dark wet	13.104 ±0.191	32.229 ±0.486	21.805 ±0.157	53.806 ±1.978	24.35 ±1.240	59.820 ±5.108	4.476 ±0.162	11.120 ±0.708
Light dry	14.567 ±0.198	40.142 ±1.491	22.973 ±0.232	63.154 ±0.852	26.03 ±0.892	71.890 ±4.137	3.695 ±0.133	10.131 ±0.127
Light wet	12.688 ±0.134	26.094 ±0.849	14.232 ±0.458	25.056 ±0.330	24.44 ±0.076	50.348 ±1.031	3.441 ±0.063	7.096 ±0.250

*m.f.: moisture-free basis; res.: residual dry-weight basis. See text for explanation.

TABLE III

Increase in Percentages of Carbohydrates during 7 Hours' Exposure to Light

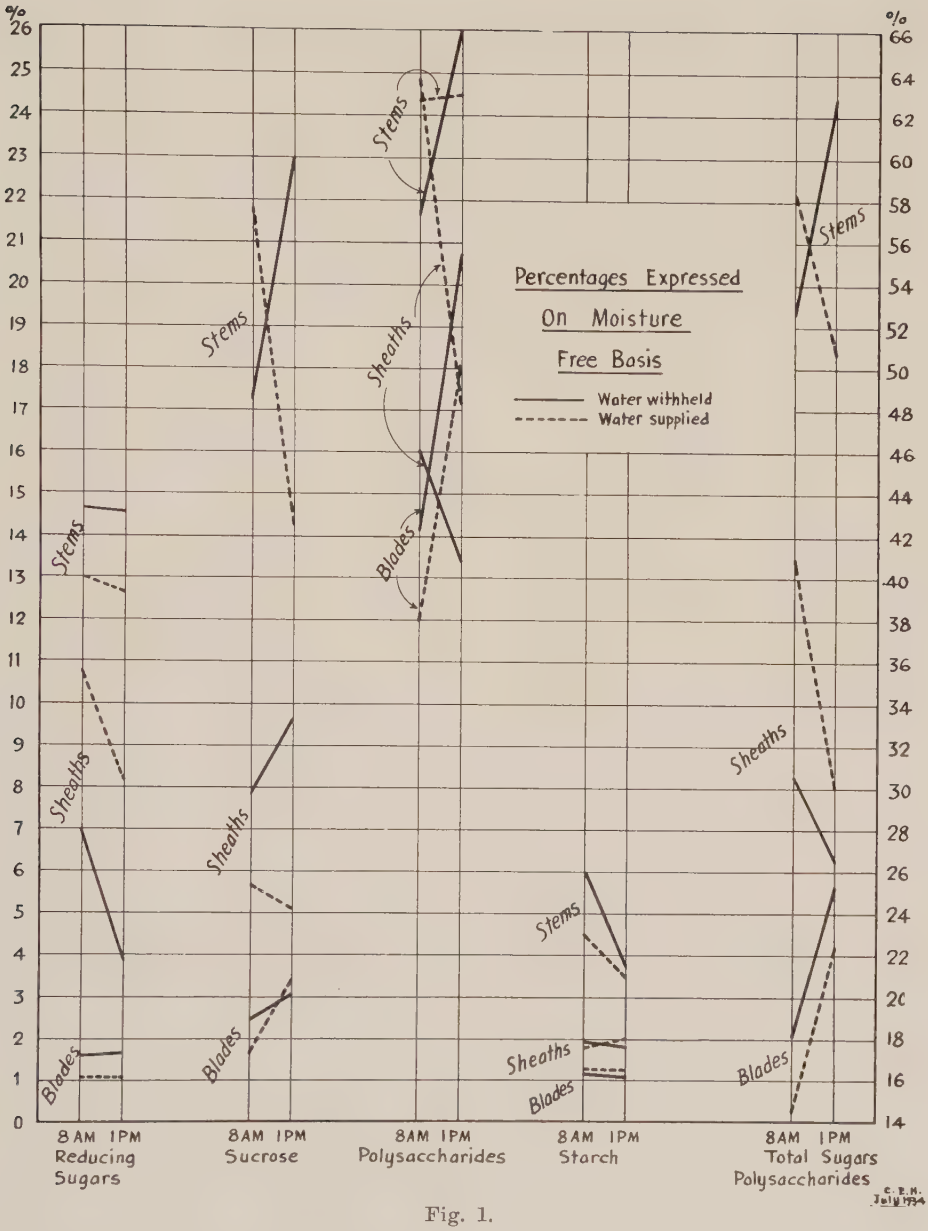
Carbohydrate	Blades		Sheaths		Green-leaf Cane	
	m.f.*	res.*	m.f.	res.	m.f.	res.
Reducing Sugars:						
Water withheld	0.065	0.298	—3.136	—4.857	—0.075 (not sig.)	8.668
Water supplied	—0.024 (not sig.)	0.100 (not sig.)	—2.603	—6.844	—0.416 (not sig.)	—6.135
Sucrose:						
Water withheld	0.646	1.001	1.972	1.889	5.759	26.035
Water supplied	1.769	2.490	—0.629 (not sig.)	—2.531	—7.573	—28.750
Polysaccharides:						
Water withheld	6.48	10.191	—2.69	—4.889	4.41	25.366
Water supplied	6.20	9.452	—7.76	—18.475	0.09	—9.472
Starch:						
Water withheld	—0.105 (not sig.)	—0.108 (not sig.)	—0.097	—0.281	—2.268	8.780
Water supplied	—0.052	0.086	0.195	—0.261	—1.035	—4.024
Polysaccharides (excluding starch):						
Water withheld	6.678	10.299	—2.594	—4.608	6.677	28.745
Water supplied	6.253	9.366	—7.961	—18.214	1.129	—5.448
Total Sugars+Polysaccharides:						
Water withheld	7.06	11.443	—3.96	—7.695	10.24	59.918
Water supplied	7.90	6.974	—10.91	—27.555	—7.54	—38.834

*m.f.: moisture-free basis; res.: residual dry-weight basis.

Discussion

The amount of sugar in millable cane depends upon numerous factors, including the rate of photosynthesis in the leaves, the utilization of sugar in growth and respiration, the rate of translocation from the blades through the sheaths into the stems, and the transformations among the carbohydrates in the stem including further synthesis of sucrose. One of the most important means possessed by the sugar planter which enables him to control the physiological processes within the plant is the regulation of the water supply. The common practice on irrigated plantations is to stimulate growth by adequate applications of water, and then withhold water for a period of approximately three months before harvest to decrease growth and enrich the juices.

The question arises as to whether the enrichment of the juices following the withholding of water, indicated by a decrease in quality ratio, is caused by an increase in sugar or by a decrease in water. If merely the latter, it may be that plantation men are deceiving themselves and that an actually greater tonnage of sugar would be obtained if irrigations were continued nearer to the time of harvest. It is known that water is necessary for photosynthesis and translocation, and evidence is presented in this paper which may indicate that both these processes occur better in cane plants adequately supplied with water. On the other hand, it is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Percentages Expressed
On Moisture
Free Basis
Water withheld
Water supplied
Stems
Sheaths
Blades
8AM 1PM
Reducing Sugars
Sucrose
Polysaccharides
Starch
Total Sugars
Polysaccharides
C. E. M.
July 1934

Fig. 1.

known that water stimulates growth and aids the hydrolysis of sucrose giving reducing sugars used in growth. In cane plants supplied with water, which is the greater, the loss in sugar due to stimulated growth or the gain in sugar due to photosynthesis? It is felt that the experiment now reported raises the necessity of studying this important question further, and the aim of the next experiment will be to obtain a decisive answer one way or the other.

The point at issue is somewhat clouded by the well-known fact that a rain occurring after a cane field has been dried off may result in a considerable loss in sucrose. Such a result would naturally follow hydrolysis due to increased moisture content. The point to be determined is rather this: Which will result in the greater tonnage of sugar, the usual process of withholding water for about three months prior to harvest, or continuing the irrigations?

This question cannot be fully answered from a practical standpoint without a due consideration of the sugar-producing value of the water that is withheld from a given field prior to harvest if placed on other fields where it is needed. This study does not enter into that phase of the question but gives recognition to it as an important part of the practical issue.

The present opinion is not unanimously in favor of withholding water. Rao (25) states that the onset of rains when the cane is ripe lowers the sucrose in the juice by inducing shooting of the buds, and that continuous moist weather without a well-defined ripening season has a similar effect on the juice. Verret, Mangelsdorf, and Lennox (30) report a cane ripening experiment at the Honolulu Plantation Company, where the cane was at its best from about 40-90 days after the last irrigation. After that there was a rapid loss in production per acre, caused by a slight decline in cane tonnage and a marked decline in juice quality. Juices were best 70 days after the last irrigation. They state that over-ripening may result in loss of sugar, loss of growing time for the next crop and injury to ratoons. That the withdrawal of water is not essential in cane ripening is shown by the growth of cane on unirrigated plantations, where rains may be very irregular. It is shown in a more striking manner by an experiment of Lyon and Brodie (19) in which a cane plant was grown for 12 months in tap water. Naturally no ripening by water withdrawal was possible, yet this plant had a quality ratio of 7.3. Renton and Bond (26) report that the general tendency on irrigated plantations is to decrease the length of the non-irrigation interval before harvest, and that serious losses result if water is taken off too long before harvest. They report an experiment at Ewa which showed that restriction of irrigation tends to depress cane yields appreciably, at the same time favorably affecting the juices enough to just about offset the loss in cane so that sugar yields are comparable. Restriction of irrigation is not effective in increasing sugar yields. In an experiment at Ewa, irrigation 35 days before harvest gave higher cane yields and in another experiment gave better juices. Renton and Bond conclude that caution must be used in the restriction of irrigation and that further investigations of this problem are needed.

The effect of withholding water upon the ripening of cane is really a physiological problem, since so many of the processes occurring within the cells of the plants are involved. Water unites with carbon dioxide in the process of photosynthesis, so that water is absolutely essential for the formation of sugar. Water

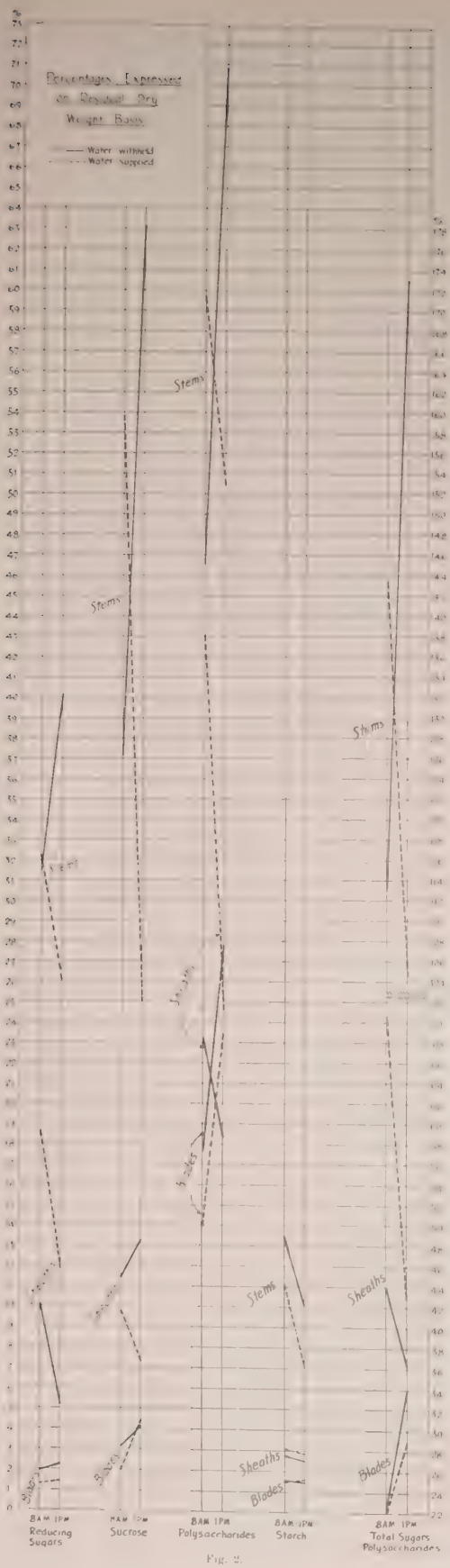
Percentages Expressed on Dry Weight Basis
Water withheld
Water supplied
Stems
Stems
Stems
Stems
Sheaths
Blades
Blades
Sheaths
Blades
8AM 1PM
Reducing Sugars
8AM 1PM
Sucrose
8AM 1PM
Polysaccharides
8AM 1PM
Starch
8AM 1PM
Total Sugars Polysaccharides

Fig. 2.

also affects photosynthesis indirectly, by maintaining the turgidity of the cells thus keeping the stomata open and allowing continuous absorption of carbon dioxide. The indirect effect upon photosynthesis is greater than the direct.

Water is the chief solvent in plants, it is the medium in which all chemical reactions occur in the plant cell, and it is the medium in which dissolved substances are translocated from the point of formation to the point of utilization or storage. The syntheses of higher compounds such as lignin, cellulose, polysaccharides, etc., are condensation processes requiring the withdrawal of water; but for the digestion of reserve polysaccharides a supply of water is necessary since digestion is a hydrolytic process. Thus, whether the processes occurring in a given cell at a given time will be mainly synthetic or mainly digestive depends largely upon whether the cell is losing or gaining water.

In considering which series of plants is the better, comparisons will be drawn and possibilities suggested, but no attempt will be made to draw a conclusion until the experiment is repeated.

The differences in moisture percentage are not large, although significant. The blades of one series of plants may undergo variation just as great during a period of 24 hours. The blades of cane plants growing in the field at the Experiment Station and receiving an adequate amount of water, varied from 66.56 per cent water (at 3 p. m.) to 70.75 per cent water (at 6 a. m.) on April 25 and 26, 1933 (15). It does not seem likely that the percentage of water in cane blades would decrease much more under the usual conditions of ripening, inasmuch as the plants used in the experiment now reported presented an appearance far worse than is usual in the field. It is recognized that withholding water decreases the photosynthetic surface by hastening the drying of the lower leaves; but it may be that the water content of the upper green leaves does not decrease enough to interfere seriously with photosynthesis. Brilliant (3) using the method of gas analysis found that with a loss of 41-63 per cent of the water content of the leaves of *Hedera helix* and *Impatiens parviflora* photosynthesis almost stopped, but a loss of about 39 per cent resulted in a rapid increase in photosynthesis. In the present experiment the decrease in water in the blades exposed to light was from 69 per cent (the "wet" blades) to 66 per cent (the "dry" blades), representing a loss of about 4 per cent of the water, which is so little that it may have had no ill effects upon photosynthesis. Miller (20) states that the effect of lack of water upon the closure of the stomata is greater than the direct effect upon photosynthesis. At the wilting point cane leaves do not droop as do the leaves of many plants, and it may be that the stomata do not close.

Reducing sugars, sucrose, and polysaccharides are all considered either direct or indirect products of photosynthesis. Table III shows that both reducing sugars and polysaccharides increased more in the blades of the plants deprived of water, whereas sucrose increased more in the blades of the plants supplied with water. Thus an answer has been obtained to an important question, as it would seem that photosynthesis occurs in the blades of cane plants at the wilting point. As mentioned in the results, the best explanation of the increase in sucrose is better synthesis of sucrose (or photosynthesis) in the plants supplied with water. It would seem that a plentiful supply of water favors the development of sucrose in the

blades, whereas a deficiency in water results in the greater synthesis of polysaccharides.

The results for reducing sugars, sucrose, and polysaccharides are consistent in sheaths and stems, and may be explained either by greater translocation or greater growth in the plants supplied with water. It is known that the control plants were growing but the others were not. However, the growth of the control plants during the 7 hours' exposure to light was almost negligible, having been estimated by Mr. Wadsworth as about a third of a centimeter per stalk in elongation. Growth during exposure to light will be accurately determined in the next experiment. If the decrease in sugar in the stems of the plants supplied with water was due to further translocation into the lower part of the stick, that should result in a greater percentage of sucrose in the dry-leaf cane of the controls, a point to be determined in the next experiment.

Possibly the blades of the plants supplied with water synthesized more sucrose than the others but the control blades were not growing while the control sheaths and stems were growing and using up both sucrose and reducing sugars.

Considering just the results herein presented, it would seem that the plants deprived of water were the better. Drying-off resulted in a considerable increase in sucrose in the green-leaf cane. Before reaching this conclusion definitely, however, the experiment must be repeated. The possibility remains that the loss of sugar in the green-leaf cane of the plants supplied with water resulted from translocation into the lower part of the stick.

Work with other plants indicates that lack of water decreases the rate of photosynthesis but increases the formation of sucrose. Kreusler (18) and Nagamatz (23) have shown that the withdrawal of water from a leaf decreases its photosynthetic activity. Thoday (29), using the half-leaf method, found that closure of stomata causes a lowered rate of photosynthesis when water is withdrawn. Dastur (5) quotes a series of references reporting that plants lacking stomata show less depression of photosynthesis upon withdrawal of water than plants having stomata. Dastur also describes a simple experiment and concludes that photosynthesis is dependent upon water content. Brilliant (3) found by gas analysis, using *Hedera helix* and *Impatiens parviflora,* that with a loss of 41-63 per cent of the water content photosynthesis practically ceased. A decrease of about 39 per cent, on the other hand, was accompanied by a rapid increase in photosynthesis. In a later contribution Dastur (6) presents results obtained by gas analyses using *Cineraria stellata, Spermannia africanum,* and *Abutilon Darwini,* which showed a close relationship between rate of carbon dioxide assimilation and water content. There was nearly a straight line relationship between assimilation rate and water content, in the same species. When comparing different species, in some cases leaves with low water content assimilated more rapidly than leaves with high water content. The theory is suggested that water shortage due to inefficiency of the conducting system eventually terminates the photosynthetic activity of a leaf. Dastur and Buhariwalla (7) found that the chlorophyll content is influenced by the water content. Dastur and Desai (8) using *Abutilon asiaticum, Ricinus communis, Helianthus annuus* and *Phaseolus vulgaris,* by gas analysis found that photosynthesis showed a closer relationship to water content than to chlorophyll

content. They suggest that the importance of water may be due to the rate of diffusion of carbon dioxide within the assimilatory cells, the removal of translocation products, and the velocity of the chemical stages of the process. Emmert and Ball (10) studied the effect of soil moisture on the availability of nitrate, phosphate, and potassium to the tomato plant, and suggested (with no experimental evidence) that one of the major effects of low soil moisture is the probable decrease in photosynthesis and general metabolic processes in the plant.

An increase in the formation of sucrose in plants deficient in water has been suggested by various workers. Iljin (17) studied many species of plants in natural habitats and found more sugar in leaves in dry habitats than in wet. Leaves of *Rumex crispus* and *R. conglomeratus* contained almost twice as much sugar withered than when turgid. His work, however, is open to criticism because no mention is made of the intensity of light in the different habitats, and no account is taken of possible effects on translocation. Holman (16) quotes Neger (24) and Molisch (21) who found that wilting hastens the disappearance of starch from starch-filled leaves. Schroeder and Herrmann (27) found that in wilting nasturtium leaves the sucrose content increases at the expense of starch, a change of which the mechanism is not fully understood. Greathouse (12) using five varieties of soy bean, sunflower, milo, and cabbage, found that with the approach of maturity the moisture content of the leaf tissue decreases rapidly, causing a corresponding increase in concentration and osmotic pressure of the sap. Plants hardened to drought have increased osmotic pressure, decreased moisture content, increased sap solutes such as sugar, and increased bound water.

Although some of the evidence just presented is open to criticism, yet the general idea seems to be that a plentiful supply of water favors photosynthesis, whereas a lack of water favors sucrose synthesis. If sucrose is the first sugar in photosynthesis, then the evidence presented above is conflicting. This is further evidence that glucose is one of the first products of photosynthesis and that sucrose is made by condensation, inasmuch as the withdrawal of water favors condensation. That this is true in cane has been suggested in previous reports (15), as well as the suggestion that the enzyme invertase is important in catalyzing the synthesis of sucrose (13, 14). Evidence that the reducing sugars condense to sucrose is found in the present experiment. If the percentages of sucrose and reducing sugars in the blades and the sheaths are compared (Table II), it will be seen that in the blades of each series there is more sucrose than reducing sugar. In the sheaths, however, there is a difference depending upon the amount of water; those of the plants deprived of water having more sucrose than reducing sugar, those of the plants supplied with water having more reducing sugar than sucrose. In the stems, again, in each series there is more sucrose than reducing sugars, except for the stems of the plants supplied with water in the light. It would seem that hydrolysis of sucrose to reducing sugars aids in the translocation of sugar through the sheaths, that the reducing sugars are condensed to sucrose upon reaching the stems, and that withholding water aids in this condensation.

Table II shows that the percentages of reducing sugars, sucrose, polysaccharides, and starch increase from the blades to the sheaths to the stems, with the exception of polysaccharides in the "light dry" sheaths. Thus in the process of

translocation sucrose seems to move against the diffusion gradient. This has been reported for cane previously (15), and in other plants by other workers, and the suggestion made that sugars may never actually pass from a cell containing less sugar to one containing more. In both sheaths and stems there is more storage tissue than phloem, and both sheaths and stems have relatively more storage tissue than do blades. The greater percentages of sucrose and reducing sugars in the sheaths and stems than in the blades may be due to the fact that the sugar in the sheaths and stems is spread out in more cells, in which case the direction of translocation would be with the diffusion gradient.

Possibly another factor aiding in the translocation of carbohydrates is their interconversion. This may be an important function of polysaccharides. Polysaccharides other than starch occur in large quantity in cane, raising the questions of what they are and what are their functions. Very little work has been done upon the polysaccharides of cane. The method of hydrolysis with weak acid gives results which probably include hemicelluloses, pentosans, plant mucilages, pectic compounds and other substances. Probably all of these occur in cane. Browne and Blouin (4) quote a proximate analysis of cane by Halligan and Agee, showing pentosans in leaves, 5.49 per cent; stalks, 3.04 per cent. The hydrolytic products of purified bagasse digested with caustic soda included some xylan and araban. Microchemical tests conducted by Crutchfield (personal communication) showed the presence of araban and xylan in the leaf and the stem. Farnell (11) studied the pectic substances of sugar cane fiber and reported the presence of pectinogen and pectin. It is felt that there is need for further study of the composition and functions of specific polysaccharides in cane.

Summary

1. Evidence is presented indicating a greater synthesis of sucrose in the blades of cane plants supplied with water than in those deprived of water. Some photosynthesis occurs in sugar cane at the wilting point.

2. Differences in reducing sugars, sucrose, and polysaccharides in the sheaths and stems may be explained by assuming either greater utilization of food by the plants supplied with water during seven hours' exposure to light, or better translocation in the same plants.

3. The experiment will be repeated in an attempt to obtain a decisive answer to the question, which is the better plant? Criticisms and suggestions from anyone interested will be appreciated.

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Phosphate Fixation in Hawaiian Soils—III

By L. E. Davis

The first paper of this series, written by Hance (3), presented a comprehensive discussion of the fixation of phosphates in Hawaiian soils. The second paper, by Ayres (1), dealt with the geographical variation of fixing power, the methods of studying the phenomenon in the laboratory and the rate at which applied phosphate is fixed.

The present paper will deal with the mechanism of phosphate fixation, that is, it will attempt to answer the question: What takes place in the soil when applied phosphates are fixed?

In order to discuss this question adequately it becomes necessary to distinguish two related but different connotations of the expression "phosphate fixation." The most important sense is that phosphate fixation is a process by which applied phosphate is rendered unavailable to the crop. The second meaning is that applied phosphate, which is at first in solution, goes out of solution when mixed with the soil. These two concepts are not quite identical because of the fact that certain almost insoluble phosphate compounds which may be precipitated under certain conditions may be still soluble enough when in contact with plant roots to slowly provide sufficient phosphate for the plants grown in the soil. For this reason simple chemical tests of phosphate fixation may not always correctly indicate that applied phosphate will be withheld from the cane due to fixation. An illustration of this fact is presented by Ayres, who found extremely high fixation in Hilo Coast soils, that is to say, these soils show an extremely high tendency to render almost completely insoluble any phosphates applied. Nevertheless, as Ayres points out, these soils are highly productive. Although they show indications of phosphate deficiency in Mitscherlich tests, and in a certain visible response to phosphate applied in

special ways in the field, increased yields due to phosphate applications, where the final yield of cane is measured in the ordinary phosphate field experiments, are not generally obtained. (There are, however, a few exceptions.) The status of these soils with respect to their need of phosphate is one that invites further study. On the other hand, there are a number of Hawaiian and other soils which fix phosphate strongly, as shown by chemical and other tests, so that as a consequence there is a decided and unquestionable deficiency of that nutrient. In many of these soils, although little or no response is shown to light fertilizations, the deficiency symptoms are largely overcome by heavy applications.

Phosphate Fixation as a Chemical Phenomenon:

We shall first discuss the chemical aspect of fixation. What happens when phosphates are removed from solution by contact with soil? We shall find that more than one thing can happen and that while some processes cause the formation of rather insoluble phosphates similar to reverted phosphate, which are, nevertheless, a source of plant food, other reactions lead to the formation of complex materials in the soil which are probably far less able to yield phosphates for the use of the plant.

Among investigators there has been considerable controversy as to the mechanism of phosphate fixation. In the opinion of the author this controversy has arisen largely because one worker was studying a type of soil in which one process was dominant, while another investigator was interested in soils in which a very different process was responsible for most of the fixation.

Fixation Caused by Precipitation:

Up to within a year or two ago almost everyone subscribed to the opinion that phosphate fixation was due to a process whereby calcium, magnesium, iron, aluminum and manganese were dissolved from the soil or replaced from the replacement complex and then formed rather insoluble compounds with applied phosphates. Russell (5), p. 199, is quite emphatic upon this point, as are other authorities. There is no doubt that this process occurs in most soils to a large extent, probably in all soils to some extent. Apparently while some plants may have difficulty in utilizing some of these insoluble forms, others undoubtedly can use some of them as shown by Marais (4) and recently by Ward and Gow, as described by Hance (3). It is very probable that in areas like the Hilo Coast this type of fixation is very important. Since phosphate so fixed is not really withheld to a harmful degree from sugar cane with its growth period of from 15 to 24 months, we shall pass on to the discussion of the more serious types of fixation which have been studied in this laboratory during the past year. In collaboration with Ayres the writer is studying possible methods for distinguishing the less troublesome types of fixation from the more harmful ones.

All of the phosphate compounds mentioned above, while rather insoluble under certain conditions of acidity or alkalinity, are somewhat more soluble at higher or lower pH values. One phosphate compound not listed above, titanium phosphate (a substance of variable composition, due to the formation of complex basic salts), is

quite insoluble in very acid up to moderately alkaline solutions. If this compound could be formed we should have a very difficultly available form of phosphate. Hawaiian soils contain large amounts of titanium and it is conceivable that under certain conditions phosphate might be fixed as titanium phosphate. However, it has been found in this laboratory that in certain high-fixing soils titanium is not responsible for more than a trace of the phosphate fixed.

Two very acid phosphate solutions were prepared. The pH of these solutions was very low, 0.5, about the pH of a solution made up with 3 cc concentrated hydrochloric acid in 100 cc of water. At this acidity all the phosphates mentioned above, except titanium, are quite soluble. (There are, of course, other insoluble phosphates of rarer metals not found to any extent in our soils.) To one of these solutions hydrogen peroxide was added but not to the other. Hydrogen peroxide prevents the precipitation of insoluble titanium phosphate. Now when soil was added to each of these solutions we should have expected less fixation in one case than in the other if fixation were due to the formation of titanium phosphate. Nevertheless the fixation was the same for both solutions. A solution of titanium sulfate was added to each filtrate obtained from the mixtures. In one case a precipitate was formed, in the other, containing hydrogen peroxide, none was formed. We see that the results were not due to any incapacity of the phosphate to precipitate titanium in one case or to failure of the hydrogen peroxide to prevent precipitation in the other case. The explanation is that the titanium compounds of the soil are so insoluble that no more than a mere trace of titanium went into solution to precipitate phosphates.

Precipitation Not the Only Cause of Fixation:

Experiments in this laboratory have demonstrated that when all the readily soluble substances which could form insoluble phosphate compounds have been removed by percolation of dilute acids or solutions of salts through the soil, the soil still possesses a pronounced fixing power. In fact in some cases it is only slightly decreased. There is thus some mechanism of fixation other than the formation of these precipitates.

The same fact is shown by the pronounced fixation in very acid solutions which is as great as that in neutral or alkaline solutions. In another experiment a soil from upper Manoa Valley was shaken for many days with very acid phosphate solutions. The pH of the solutions never became greater than 0.70. None of the phosphates except titanium could have been precipitated under these conditions. Nevertheless, as can be seen from the data below, there was pronounced fixation which increased slowly as time went on.

Time—Days	Per Cent Fixed
⅔	30.8
2½	45.0
6	55.4
10	65.7
14	72.8
27	86.5

Now since it is clear that in these acid solutions substances do not leave the solid soil and form insoluble compounds in the solution by reacting with the phosphates present, there is only one alternative: the phosphates must leave the solution and join the solid soil materials to become part of them.

Soil Colloids:

There are two ways in which this situation might occur. During the long process of weathering the original soil minerals have been decomposed into a very large number of extremely small particles. Under ordinary field conditions these particles are rather loosely held together to form the more or less continuous mass of an untilled field soil, which is then broken up into clumps by cultivation. Under certain conditions when the soil is quite moist and then thoroughly stirred, and also to some extent when it is not stirred, these particles can be separated from one another. If the particles remain separated they do not settle out rapidly but remain in suspension for some time. When the amount of water is small such a suspension becomes a pasty mass. In the field this process is called puddling; in the laboratory it is called peptization or dispersion. In most soils only a small percentage of these particles are as minute as those usually studied in colloidal chemistry and which are technically known as colloids. However, there is no sharp division of particle size below which the particles exhibit the properties of colloids, or above which they do not. Since the soil particles approach the size of what are usually called colloids, they partake to a large extent of the properties of the latter and are usually, therefore, called soil colloids. One of the consequences of dividing a material into very small particles is to increase the total surface; another result may be an increase in the curvature of the surface.

Fixation Due to Adsorption:

All surfaces have the capacity to attract and hold in some way various substances. This property is called adsorption. Adsorption tends to be greater on curved surfaces than on plane surfaces. An enormous number of colloidal particles, presenting a large extent of sharply curved surface may have a high power of adsorption. An extremely porous material will have a similar power since there is then a large internal curved surface. It is the power to retain certain colored substances that makes bone char so useful in sugar refining.

It is conceivable that adsorption plays a part in phosphate fixation. It is probable that it does not play a very large part. In the first place the power of soils to adsorb most acidic radicals, such as sulfates, chlorides, nitrates, etc., is not very great. From the data above we see that in 27 days, even in a very acid solution, 86 per cent of the phosphate had been fixed. In an experiment, the data from which it is not necessary to present in detail here, ammonium chloride solutions were shaken with portions of this Manoa soil. Less than 3 per cent of the chloride was fixed at any concentration over a wide range, and it is by no means certain that all of that 3 per cent was fixed by adsorption. It should be surprising to find that phosphates are an exception unless there were some specific chemical relation between phosphates and the soil minerals to cause such an extraordinary increase in adsorption.

Occasionally it is stated that in phosphate solutions we have PO_4 ions which are trivalent negative ions. Trivalent negative ions have the power of combining with three times as much potassium or sodium as monovalent ions of which chloride ions are an example. It is further stated that in general, trivalent ions are more strongly adsorbed than monovalent ions like chloride ions, and that this would account for the alleged great adsorption of phosphates. There are two misconceptions in these statements. In the first place in acid, neutral, and moderately alkaline solutions phosphates yield only extremely small quantities of trivalent PO_4 ions, a fact well known to chemists. The ions present in phosphate solutions at neutral, acid or moderately alkaline reaction are the monovalent ions H_2PO_4 and the divalent ions HPO_4. In the second place there is no evidence in the literature to show that even where we certainly have such ions the adsorption of ions increases greatly and consistently with their valence.

True adsorptions are usually very rapid and are completed in a matter of minutes rather than days. We see phosphate fixation still not completed after 27 days. In another experiment with this Manoa soil, in a neutral solution, fixation was not completed at the end of 85 days of constant agitation of the mixture of soil and solution. Unless we have no other explanation, adsorption is not a very satisfactory one.

Solid Solutions and Absorption:

There is, however, another way in which a solid material can react with various substances in a solution which is in contact with the solid substance. Solids are not quite as impervious as we ordinarily suppose. Under certain conditions it is possible for one substance to be so intimately interfused with another that we have in the solid state a true solution. Such solutions are called solid solutions and they are usually formed by the cooling of liquid solutions. Some slags, alloys, etc., are examples. Some melts do not cool to a system of solid solution but separate as distinct, although very minute crystals. A solution of common salt in water, when frozen, becomes a mixture of ice and salt.

Solid solutions can also be formed by liquids, solids or substances in solution diffusing into the solid material. This process is usually very slow and it has not been very widely studied, so examples are not numerous: gases dissolve in certain metals, water is taken up by many solids (in many cases this is probably adsorption), thallium nitrate in aqueous solution diffuses into solid potassium nitrate, many organic liquids diffuse into organic solids, mercury is taken up by many metals. In the latter case there is a special reason for the reaction. The metals tend to dissolve in the mercury with the formation of mercury-metal compounds. These substances are called amalgams.

When a chemical reaction occurs between the diffusing substance and the material into which it diffuses, the tendency for fixation becomes very great. Such a process is called absorption. Adsorption, the fixation of substances upon surfaces, and absorption, the fixation of substances in the interior of solids, are sometimes collectively called sorption, a term which is useful when we are certain that either adsorption or absorption occurs but are not quite certain which takes place.

New compounds are formed and may be said to exist in solid solution along with the absorbent (the original solid material) and the absorbed substance.

Gels—A Form of Colloids:

Before applying this discussion to the fixation of phosphates we must digress a moment. Besides the three ordinary states of matter, gaseous, liquid and crystalline (or solid), we have mentioned what is in a sense a fourth state, that of extreme division or dispersion into colloidal particles. It is possible to speak of a fifth state. This arises when under certain conditions the colloidal particles come together and coalesce, usually with considerable water, to form gelatinous masses. A few drops of acid rapidly mixed with common water glass will form such a gelatinous mass. These substances are called gels. (The ordinary suspensions of dispersed particles are called sols.) Now it is generally believed that in gels the original minute particles are still present and are either surrounded by water or consist of a network which encloses the water. There is still considerable uncertainty about the structure of gels.

Gels have a pronounced capacity for sorption. Generally this is considered to be due to adsorption on the surfaces of the small particles composing the gel. But in a sense the gel as a whole may be said to absorb substances. The rate is sometimes quite slow, particularly with some gels into which diffusion is slow. It is possible to consider sorption by gels as a case intermediate between adsorption by sols and absorption by solids.

Fixation Due to Absorption:

In soil we undoubtedly have present besides organic matter, air and water, crystals and amorphous solids. Some of the solids are present, as we have seen, in a state of fine division. It is also probable that gels or gel-like flocs are present. There is some controversy upon this point which need not concern us here. The colloidal matter in an undispersed dry soil has many of the characteristics of aged, desiccated gels which, by vigorous peptization with both mechanical and chemical agents can be moderately dispersed. This consideration makes clear a paradox. The relative fixing power of a soil may be related to the amount of colloidal matter (gel) in the soil; it is not necessarily related to the number of very small particles as estimated by a sedimentation analysis.

Whatever may be the best term to use in describing the solids in the soil, the fixation of phosphate has all the characteristics of absorption. The fixation is rapid at first, which may be due to reactions occurring at or near the surface; subsequently the rate decreases, but the process continues for a long time, which one would expect if the diffusion is quite slow. Fixation is specific, that is, certain substances, phosphates and arsenites are strongly fixed; others, such as chlorides, sulfates, ferrocyanides (in alkaline solutions, the latter should yield not only trivalent ions, but quadrivalent ions) are not.

Phosphate fixation may then be considered as due to three processes: (1) bases such as Ca, Mg, Fe, Al, Mn present in the soil go into solution and react with phosphates to form insoluble phosphates. (2) phosphates are adsorbed upon the

colloidal surfaces. (3) phosphates slowly diffuse out of the solution into some of the amorphous solids of the soil. They combine with materials in these solids. Probably hydrated iron and aluminum oxides combine with phosphates to form complex compounds. It is believed that in upland Hawaiian soils the third process predominates.

Only a part of the evidence for this picture has been presented. There is available a great deal of evidence experimentally obtained in this laboratory and some corroborative evidence in the literature, notably the results of recent researches by Dean (2). Certain characteristics of the equilibrium curves obtained from fixation experiments; the fact that more phosphate is fixed in acid solutions than in neutral or alkaline solutions; the fact that bases, such as potassium, are fixed along with the phosphate, etc., can be interpreted as evidence supporting the conclusions. The discussion of these points is, however, rather technical and is omitted.

Agricultural Significance of Phosphate Fixation:

In the first part of this paper we stated that there were two different meanings of the term "phosphate fixation". We shall now turn to the first meaning which is less technical and also of more importance to agriculture. Phosphate fixation means to the man who is concerned with sugar cane yields a process whereby, whatever the cause, the plant cannot find available a part, large or small, of phosphate applied as fertilizer.

Obviously phosphate precipitated in the form of compounds which readily yield phosphorus to the plant roots is not fixed in this sense. Such precipitation not only does no harm; it is of undoubted benefit in preventing excessive leaching of phosphate.

Beyond this, however, there are two things to consider in regard to the absorption of phosphates. In the first place the reaction is quite slow, even when the soil is finely powdered and continuously shaken with a large amount of solution. It is probably much slower when applied as a top dressing or when merely mixed with moist soil. During the interval following fertilization there must be at first considerable available phosphate and later appreciable amounts.

Phosphate Absorption a Reversible Equilibrium:

The second consideration is concerned with the very nature of the process. We have abundant evidence to show that phosphate absorption is a reversible equilibrium. In truth this fact constitutes part of the evidence in favor of the absorption hypothesis. By a reversible equilibrium we mean that the process has a tendency at all times to go in both directions and that this tendency is controlled by the relative amounts of the substance taking part in the process.

A crude analogy can be found in the state of affairs which occurs, for example, when a number of people are visiting a series of exhibits in different rooms at a county fair, and are permitted to pass freely from one room to another. The number of people passing from one room to another depends upon the number of people in each room to a certain extent. Some rooms are more crowded than

others because the exhibits are more interesting, but in general some people will leave when they cannot see or hear easily. This situation is quite different from an entertainment at a theater where the crowd enters at one time and later leaves in a body.

In absorption, as in most chemical reactions, the more phosphate in solution, that is, the more the solution is crowded, the more will tend to enter the soil and be fixed. For this reason one cannot speak of "the fixing power of the soil" as an absolute quantity in terms of pounds P_2O_5 per acre, or of "saturating the fixation complex". Likewise, the more phosphate fixed in the soil the more will tend to leave the soil and return to the solution. We shall now consider what happens when, as we say, the system reaches equilibrium. Then, there is obviously a balance set up. The important point is that at this time some phosphate must remain in solution; the amount may be very small. Instead of asking how much phosphate is required to completely saturate the soil, one should ask how much is required to retain a certain minimum concentration in the soil solution. This point has been emphasized by Ayres.

If the balance is upset in any way, an adjustment must take place. The balance can be temporarily upset by leaching out the phosphate in solution or by assimilation of that phosphate by plant roots. Now, if the amount of phosphate in solution is temporarily enough for proper nutrition of the plant more will be forthcoming from the fixed supply, provided the requirements of the plant are not so great that assimilation is very much more rapid than the reversal of fixation. There is, of course, a limit to this process since as the fixed supply decreases its tendency to enter the solution decreases also and the amounts available to the plant decrease. In this connection it may be noted that probably a highly dispersed soil not alone fixes phosphate more quickly but will also release it more rapidly. This fact may account for some of the apparent conflict between chemical tests and agricultural experience.

All this is quite different from the case of a plant obtaining its nutrition from a solution surrounding a solid compound which is not in solid solution. In this case the amount of the solid compound has no effect upon the amount which goes into solution. (The extent of surface exposed has an effect upon the rate at which the material goes into solution.) This is analogous to the case of an exhibit to which only a definite number are admitted at any time. Obviously the number of people in an adjacent room would not affect the number visiting this particular exhibit.

Conclusions

Phosphate fixation is not invariably an unmitigated evil. It is a means whereby applied phosphates are conserved and as long as sufficient phosphate remains available to the crop it is a blessing. Whenever high phosphate fixation is suspected in a field soil it is probably best to supplement the results of rapid chemical tests by other considerations to be obtained from more refined chemical tests, Mitscherlich tests, field experiments, and, most important of all, as shown in the case of the Hilo Coast soils, the general agricultural experience with the soils.

There are probably cases of moderate fixation of such character that response

to light applications is not apparent, but where moderately high applications would raise the level of phosphate fixed to the point where there is sufficient of this nutrient available. The question will then be asked: Can this expensive fertilization be followed by light applications for a number of years? This is, of course, the crux of the whole matter. There is a vast difference between a moderately great fertilization followed by light applications and the unwelcome prospect of continued heavy applications. There is, however, every reason to believe that once a reasonable available supply is made possible this can be maintained by light fertilizations for some time. Needless to say, if the uptake of phosphorus by the crop exceeds the amount applied as fertilizer, the soil will be gradually depleted again.

When fixation is so intense that only large fertilizations can raise the phosphate level sufficiently it is believed that fertilizer briquettes or the less soluble phosphatic materials will supply sufficient plant food without losing their phosphate to the fixation complex of the soil.

Summary

1. A theory of the mechanism of phosphate fixation is presented.

2. Two connotations of the expression "phosphate fixation" are considered. Not all phosphate removed from solution and therefore classed as fixed in one sense of the term is actually unavailable to crops and therefore fixed according to the second meaning of the expression.

3. Some phosphate is fixed by reaction with soluble or replaced soil bases to form precipitates.

4. It is shown that precipitation does not account for the greater part of fixation in upland Hawaiian soils.

5. The nature of soil colloids and their relation to phosphate fixation is discussed.

6. It is concluded that adsorption by the soil colloids is a minor cause of phosphate fixation.

7. The single alternative explanation for phosphate fixation is that phosphates are absorbed by the soil material, that is, they actually penetrate the solid phase to react and form new compounds in solid solution.

8. It is shown that while most of the absorbed phosphate is not immediately available, an equilibrium concentration of available phosphate is maintained in the soil solution.

9. Due to the slow rate of fixation, some available phosphate remains for some time after fertilization.

10. Fixation is not entirely harmful. It conserves the phosphate supply.

11. In some cases it may be feasible to build up a phosphate reserve by an initial heavy fertilization, followed by lighter applications. In other cases this may not be practicable, and phosphates should probably be supplied in briquettes or in insoluble forms.

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For Better Field Experiments With Fertilizers

By R. J. Borden and Y. Kutsunai

These "plans of fertilization" and "arrangements of treatments" are offered as examples for better "Grade A" field experiments that are primarily concerned with fertilizer issues. We believe that results which may be obtained from such plans can be suitably interpreted and differences can be measured with considerable confidence that they are the effect of the treatments applied.

In the plans of fertilization that are given here we would avoid overly large single applications of soluble nitrogen or potash salts, with the feeling that such is a safer procedure to follow in our field experiment work. Hence, no single application of nitrogen greater than 100 pounds, or of potash greater than 150 pounds is recommended (unless size of dose is the variable being tested). Concerning phosphate, we believe that wherever possible this material should all be applied to plant cane in the furrow with the seed, and in a small off-bar furrow to ratoons as soon as they are started. We would generally avoid surface applications of phosphate, especially of the insoluble forms.

Naturally it is impossible to give plans to fit every condition that will exist. It will probably be necessary to make some changes in the constants that are suggested. One may wish to allow for more, or for less, of those plant foods that are not concerned in the differential treatments, depending on the available natural or soil supplies. However, it will be well to make sure that the amounts allowed for these constants will not become a controlling factor for the experiment.

In submitting arrangements of treatments we have indicated what we believe are the preferred layouts as well as alternative layouts that are acceptable. Our objectives for these preferred designs have been as follows:

(1) Either to locate the most desired comparisons on adjacent plots, thus making them suitable for analysis of the average yield differences by Student's method, or to arrange treatments in blocks (one plot of each treatment in each block) in a manner that is suited for the application of Fisher's analysis of variance to the results.

(2) To provide for a balance of a possible fertility slope that might exist in the test area and cause unfair comparisons.

(3) To reduce the border effect between treatments.

Thus several new arrangements are offered that appear to meet the desired objectives slightly better than some of the older arrangements have done in previously used fertilizer tests. These may not necessarily be preferred arrangements for all tests, since in some cases the harvest- and separation-errors of the outer lines of adjacent plots are liable to be greater than the errors due to border effect. Then too, a reduction in this border effect can be obtained if the differential fertilizer applications to adjacent plots are made on the inner side of each plot's border rows. However, these new arrangements are offered for consideration and trial in our efforts toward building for better field experiments with fertilizers.

SOME APPROVED "GRADE A" PLANS FOR FERTILIZATION AND ARRANGEMENTS OF TREATMENTS

Kind of Experiment: PLANT FOOD (PK)

Plan of Fertilization								Pounds per Acre Totals		
Treat-	(1)	(2)		(3)		(4)	(5)			
ments	P_2O_5	N	K_2O	N	K_2O	N	N	N	P_2O_5	K_2O
A	200	40	0	60	0	50	50	200	200	0
B	200	40	100	60	100	50	50	200	200	200
C	0	40	100	60	100	50	50	200	0	200
D	0	40	0	60	0	50	50	200	0	0

Arrangement: No. 20, 25 or 19.

Kind of Experiment: AMOUNTS OF NITROGEN (AN)

Plan of Fertilization								Pounds per Acre Totals		
Treat-	(1)			(2)		(3)	(4)			
ments	N	P_2O_5*	K_2O	N	K_2O	N	N	N	P_2O_5	K_2O
A	50	100	150	50	150	50	0	150	100	300
X	50	100	150	75	150	75	0	200	100	300
B	50	100	150	100	150	100	0	250	100	300
or B	50	100	150	70	150	65	65	250	100	300

* This may be a surface application.

Arrangement: No. 6, 7, 8, 9, 10, 11, 12, 13, 14, or 15.

Kind of Experiment: AMOUNTS OF NITROGEN (AN)

Plan of Fertilization						Pounds per Acre Totals		
Treat-	(1)			(2)	(3)			
ments	N	P_2O_5*	K_2O	N	N	N	P_2O_5	K_2O
A	41	300	150	42	42	125	300	150
X	58	300	150	58	59	175	300	150
B	75	300	150	75	75	225	300	150

* On plant cane this P_2O_5 would go on with the seed; on ratoons it would be put in the subsoil or off-bar furrow.

Arrangement: No. 6, 7, 8, 9, 10, 11, 12, 13, 14, or 15.

NOTE: The numerals in parentheses—(1), (2), (3), (4), (5)—indicate the first, second, third, fourth and fifth applications of fertilizer respectively.

Kind of Experiment: AMOUNTS OF NITROGEN (AN)

Plan of Fertilization								Pounds per Acre Totals		
Treatments	(1) N	(1) P_2O_5	(1) K_2O	(2) N	(2) K_2O	(3) N	(4) N	N	P_2O_5	K_2O
A	40	150	125	60	125	0	0	100	150	250
B	40	150	125	60	125	50	0	150	150	250
C	40	150	125	60	125	50	50	200	150	250
D	40	150	125	60	125	75	75	250	150	250

Arrangement: No. 17, 19, or 23.

Kind of Experiment: AMOUNTS OF NITROGEN (AN)

Plan of Fertilization									Pounds per Acre Totals		
Treatments	(1) N	(1) P_2O_5*	(1) K_2O	(2) N	(2) K_2O	(3) N	(4) N	(5) N	N	P_2O_5	K_2O
A	40	200	100	35	100	0	0	0	75	200	200
B	40	200	100	50	100	60	0	0	150	200	200
C	40	200	100	50	100	60	75	0	225	200	200
D	40	200	100	75	100	60	75	50	300	200	200

* On plant cane this 200 pounds could be put in with the seed, and the N and K_2O later (at 4 to 6 weeks).

"A" or "D" may be omitted.

Arrangement: No. 17, 19, or 23.

Kind of Experiment: AMOUNTS OF NITROGEN (AN)—Extra N in second season.

Plan of Fertilization							Pounds per Acre Totals		
Treatments	(1) N	(1) P_2O_5	(1) K_2O	(2) N	(3) N	(4) N	N	P_2O_5	K_2O
X	50	150	150	62	63	0	175	150	150
A	50	150	150	62	63	50	225	150	150

Arrangement: No. 1, 2, 3, 4, or 5.

Kind of Experiment: AMOUNTS OF NITROGEN (AN)

Plan of Fertilization							Pounds per Acre Totals		
Treatments	(1) N	(1) P_2O_5	(1) K_2O	(2) N	(3) N	(4) N*	N	P_2O_5	K_2O
X	30	100	150	30	35	80	175	100	150
A	30	100	150	55	60	80	225	100	150
B	30	100	150	80	85	80	275	100	150

* This second season nitrogen may be applied in two 40-pound applications.

Arrangement: No. 6, 7, 8, 9, 10, 11, 12, 13, 14, or 15.

Kind of Experiment: AMOUNTS OF PHOSPHATE (AP)—For plant or ratoons.

Plan of Fertilization							Pounds per Acre Totals		
Treatments	(1) P_2O_5*	(2) N	(2) K_2O	(3) N	(3) K_2O	(4) N†	N	P_2O_5	K_2O
X	0	60	125	60	125	80	200	0	250
A	100	60	125	60	125	80	200	100	250
B	200	60	125	60	125	80	200	200	250
C	400	60	125	60	125	80	200	400	250

* Applied with the seed for plant cane, preferably in the subsoil or off-bar furrow for ratoons if treatment "C" is included. (See note.)

† This N may be split into two 40-pound doses. Treatment "C" may not be necessary or may be at 300 pounds P_2O_5.

Arrangement: No. 18 or 22.

Kind of Experiment: AMOUNTS OF PHOSPHATE (AP)—For plant or ratoons.

Plan of Fertilization								Pounds per Acre Totals		
Treatments	(1) N	(1) P_2O_5	(1) K_2O	(2) N	(2) K_2O	(3) N	(4) N	N	P_2O_5	K_2O
X	40	0	125	60	125	50	50	200	0	250
A	40	150	125	60	125	50	50	200	150	250
B	40	300	125	60	125	50	50	200	300	250

Arrangement: No. 6, 7, 8, 9, 10, 11, 12, 13, 14, or 15.

Kind of Experiment: AMOUNTS OF PHOSPHATE (AP)—For plant cane.

Plan of Fertilization						Pounds per Acre Totals		
Treatments	(1) P_2O_5*	(2) N	(2) K_2O	(3) N	(4) N	N	P_2O_5	K_2O
X	0	50	100	50	75	175	0	100
A	200	50	100	50	75	175	200	100
B	400	50	100	50	75	175	400	100
C	600	50	100	50	75	175	600	100

* Applied with the seed.

Either "B" or "C" may be omitted.

Arrangement: No. 18 or 22.

Kind of Experiment: AMOUNTS OF PHOSPHATE (AP)—For ratoons.

Plan of Fertilization								Pounds per Acre Totals		
Treatments	(1) N	(1) P_2O_5*	(1) K_2O	(2) N	(2) K_2O	(3) N	(4) N	N	P_2O_5	K_2O
X	40	0	100	60	100	50	50	200	0	200
A	40	100	100	60	100	50	50	200	100	200
B	40	200	100	60	100	50	50	200	200	200
C	40	300	100	60	100	50	50	200	300	200

* This may be a surface application. "C" may be omitted.

Arrangement: No. 18 or 22.

Kind of Experiment: AMOUNTS OF PHOSPHATE (AP)—For low phosphate fixing soils.

Plan of Fertilization									Pounds per Acre Totals		
Treatments	(1) N	(1) P_2O_5	(1) K_2O	(2) N	(3) N	(3) P_2O_5	(3) K_2O	(4) N	N	P_2O_5	K_2O
X	40	0	75	60	60	0	75	65	225	0	150
A	40	50	75	60	60	50	75	65	225	100	150
B	40	100	75	60	60	100	75	65	225	200	150
C	40	150	75	60	60	150	75	65	225	300	150

"B" or "C" may be omitted.

Arrangement: No. 18 or 22.

NOTE: In field experiments, when raw rock phosphate is used, it should be mixed into the soil and not spread upon the surface. When soluble phosphates are used, it may be advisable to avoid much mixing of them with the soil.

In AP and AK tests, the "zero" treatment should not be omitted until or unless there is definite proof that the test area responds to the plant food concerned.

Kind of Experiment: AMOUNTS OF POTASH (AK)

Plan of Fertilization								Pounds per Acre		
Treat-	(1)			(2)		(3)	(4)	Totals		
ments	N	P_2O_5	K_2O	N	K_2O	N	N	N	P_2O_5	K_2O
X	40	300	0	60	0	50	50	200	300	0
A	40	300	50	60	50	50	50	200	300	100
B	40	300	100	60	100	50	50	200	300	200
C	40	300	150	60	150	50	50	200	300	300

"C" may be omitted.

Arrangement: No. 18 or 22.

Kind of Experiment: AMOUNTS OF POTASH (AK)

Plan of Fertilization								Pounds per Acre		
Treat-	(1)			(2)		(3)		Totals		
ments	N	P_2O_5	K_2O	N	K_2O	N	K_2O	N	P_2O_5	K_2O
X	50	150	0	50	0	75	0	175	150	0
A	50	150	125	50	0	75	0	175	150	125
B	50	150	125	50	125	75	0	175	150	250
C	50	150	125	50	125	75	125	175	150	375

"C" may be omitted.

Arrangement: No. 18 or 22.

Kind of Experiment: AMOUNTS OF POTASH (AK)

Plan of Fertilization									Pounds per Acre		
Treat-	(1)			(2)		(3)	(4)	(5)	Totals		
ments	N	P_2O_5	K_2O	N	K_2O	N	N	N	N	P_2O_5	K_2O*
X	30	100	0	70	0	50	50	50	250	100	0
A	30	100	75	70	75	50	50	50	250	100	150
B	30	100	150	70	150	50	50	50	250	100	300

* These totals may be 0-200-400 respectively, with the K_2O to be applied in 2 doses, i.e., 100-100 pounds and 200-200 pounds to "A" and "B" treatments.

Applications 3 and 4, or 4 and 5 may be combined, i.e., at 100 pounds N.

Arrangement: No. 6, 7, 8, 9, 10, 11, 12, 13, 14, or 15.

Kind of Experiment: AMOUNTS OF NITROGEN AND POTASH (ANK)

Plan of Fertilization										Pounds per Acre		
Treat-	(1)	(2)		(3)		(4)		(5)		Totals		
ments	P_2O_5	N	K_2O	N	K_2O	N	K_2O	N		N	P_2O_5	K_2O
A	200	50	125	50	125	50	0	50		200	200	250
B	200	50	125	75	125	75	0	75		275	200	250
C	200	50	125	75	125	75	100	75		275	200	350
D	200	50	125	50	125	50	100	50		200	200	350

Arrangement: No. 20, 25 or 19.

Kind of Experiment: AMOUNTS OF PHOSPHATE AND POTASH (APK)

Plan of Fertilization								Pounds per Acre		
Treat-	(1)	(2)		(3)		(4)		Totals		
ments	P_2O_5*	N	K_2O	N	K_2O	N	K_2O	N	P_2O_5	K_2O
A	200	75	125	75	125	75	0	225	200	250
B	600	75	125	75	125	75	0	225	600	250
C	600	75	150	75	200	75	150	225	600	500
D	200	75	150	75	200	75	150	225	200	500

* Applied with seed.

Arrangement: No. 20, 25 or 19.

Kind of Experiment: AMOUNTS OF NITROGEN AND PHOSPHATE (ANP)

Plan of Fertilization								Pounds per Acre Totals		
Treatments	(1)	(2)		(3)		(4)	(5)			
	P_2O_5	N	K_2O	N	K_2O	N	N	N	P_2O_5	K_2O
A	200	50	100	50	100	50	50	200	200	200
B	200	50	100	75	100	75	75	275	200	200
C	600	50	100	75	100	75	75	275	600	200
D	600	50	100	50	100	50	50	200	600	200

Arrangement: No. 20, 25 or 19.

Kind of Experiment: AMOUNTS OF NITROGEN, PHOSPHATE AND POTASH (ANPK)

Plan of Fertilization								Pounds per Acre Totals		
Treatments	(1)			(2)		(3)	(4)			
	N	P_2O_5	K_2O	N	K_2O	N	N	N	P_2O_5	K_2O
A	200	30	150	40	150	40	40	150	200	300
B	200	50	150	50	150	50	50	200	200	300
C	200	50	0	60	0	70	70	250	200	0
D	200	50	75	60	75	70	70	250	200	150
E	0	50	150	60	150	70	70	250	0	300
F	100	50	150	60	150	70	70	250	100	300
X	200	50	150	60	150	70	70	250	200	300

Arrangement: No. 31.

Kind of Experiment: AMOUNTS AND FORMS OF PHOSPHATE (AFP)—For Plant Cane

Plan of Fertilization							Pounds per Acre Totals		
Treatments	(1)	(2)		(3)		(4)			
	P_2O_5*	N	K_2O	N	K_2O	N†	N	P_2O_5	K_2O
X—no P_2O_5	0	60	100	60	100	80	200	0	200
A—superphosphate	200	60	100	60	100	80	200	200	200
B—superphosphate	400	60	100	60	100	80	200	400	200
C—rock phosphate	400	60	100	60	100	80	200	400	200

* Applied with seed.

† May be put on in 2 doses; 40 pounds and 40 pounds.

Arrangement: No. 18 or 22.

Kind of Experiment: AMOUNTS AND FORMS OF PHOSPHATE (AFP)—For Plant Cane Only

Plan of Fertilization						Pounds per Acre Totals		
Treatments	(1)	(2)		(3)	(4)			
	P_2O_5*	N	K_2O	N	N	N	P_2O_5	K_2O
X—no P_2O_5	0	40	150	80	80	200	0	150
A—superphosphate	150	40	150	80	80	200	150	150
B—rock phosphate	150	40	150	80	80	200	150	150
C—rock phosphate	600	40	150	80	80	200	600	150
D—superphosphate	600	40	150	80	80	200	600	150

* Applied with seed.

Arrangement: No. 27, 28 or 29.

Kind of Experiment: FORMS OF NITROGEN (FN)

Plan of Fertilization							Pounds per Acre		
Treat-	(1)			(2)	(3)	(4)	Totals		
ments	N	P_2O_5	K_2O	N	N	N	N	P_2O_5	K_2O
X—amm. sulp.	30	200	150	35	30	30	125	200	150
A—amm. sulp.	40	200	150	60	60	40	200	200	150
B—nit. soda	40	200	150	60	60	40	200	200	150
C—nit. lime	40	200	150	60	60	40	200	200	150
or C—urea	40	200	150	60	60	40	200	200	150

Either "B" or "C" may be omitted.

Arrangement: For 3 "forms": No. 16, 21 or 24.
For 2 "forms only": No. 6, 7, 10, 11, 13 or 15.

Kind of Experiment: FORMS OF PHOSPHATE (FP)

Plan of Fertilization						Pounds per Acre		
Treat-	(1)	(2)		(3)	(4)	Totals		
ments	P_2O_5*	N	K_2O	N	K_2O	N	N	P_2O_5	K_2O
X—no P_2O_5	0	50	125	60	125	65	175	0	250
A—superphos.	200	50	125	60	125	65	175	200	250
B—rock phos.	200	50	125	60	125	65	175	200	250
C—rev. phos.	200	50	125	60	125	65	175	200	250

* Applied with seed.

"C" may or may not be included.

Arrangement: For 3 "forms": No. 16, 21 or 24.
For 2 "forms only": No. 6, 7, 10, 11, 13 or 15.

Kind of Experiment: FORMS OF POTASH (FK)

Plan of Fertilization							Pounds per Acre		
Treat-	(1)			(2)		(3)	(4)	Totals		
ments	N	P_2O_5	K_2O	N	K_2O	N	N	N	P_2O_5	K_2O
X—No K_2O	40	300	0	60	0	60	65	225	300	0
A—Muriate	40	300	150	60	100	60	65	225	300	250
B—Sulp.	40	300	150	60	100	60	65	225	300	250

Arrangement: No. 6, 7, 10, 11, 13 or 15.

Kind of Experiment: FORMS OF NITROGEN AND POTASH (FNK)

Plan of Fertilization						Pounds per Acre			
Treat-		(1)				(2)			
ments	Super	A.S.	N.P.	N.S.	M.P.	A.S.	N.P.	N.S.	M.P.
X—Amm. Sulp.+Mur. Pot.	975	100	...	...	155	180	...	...	155
A—Amm. Sulp.+Mur. Pot.	975	146	...	...	155	293	...	...	155
B—Nitrate Potash	975	...	200	...	...	...	400	...	...
C—Nit. Soda+Mur. Pot.	975	...	...	195	155	...	...	385	155

Treat-	(3)			(4)			Totals		
ments	A.S.	N.P.	N.S.	A.S.	N.P.	N.S.	N	P_2O_5	K_2O
X	180	...	...	150	...	...	125	200	186
A	293	...	...	243	...	...	200	200	186
B	...	400	...	...	333	...	200	200	186
C	...	...	385	...	...	325	200	200	186

Analysis: Super at 20.5% P_2O_5.
Nit. Potash at 15% N, 14% K_2O.
Mur. Potash at 60% K_2O.
Amm. Sulp. at 20.5% N.
Nit. Soda at 15.5% N.

Arrangement: No. 16, 21, or 24.

Kind of Experiment: TIME TO APPLY NITROGEN (TN)

Treatments	Plan of Fertilization (1) N	P_2O_5	K_2O	(2) N	(3) N	(4) N	(5) N	Pounds per Acre Totals N	P_2O_5	K_2O
	First Season					Second Season				
X	40	150	150	0	40	0	40	120	150	150
A	40	150	150	40	40	40	40	200	150	150
B	120	150	150	0	0	40	40	200	150	150
C	40	150	150	80	0	80	0	200	150	150
D	40	150	150	80	0	40	40	200	150	150

"D" may or may not be included.

Arrangement: With treatment "D" included—No. 27, 28 or 29.
Without treatment "D"—No. 16, 21 or 24.

Kind of Experiment: TIME TO APPLY PHOSPHATE (TP)

Treatments	Plan of Fertilization (1) N	P_2O_5	K_2O	(2) N	P_2O_5	(3) N	P_2O_5	Pounds per Acre Totals N	P_2O_5	K_2O
A	50	200	100	60	0	65	0	175	200	100
B	50	100	100	60	0	65	100	175	200	100
C	50	70	100	60	65	65	65	175	200	100
X	50	0	100	60	0	65	0	175	0	100

Arrangement: No. 16, 21 or 24.

Kind of Experiment: TIME TO APPLY POTASH (TK)

Treatments	Plan of Fertilization (1) N	P_2O_5*	K_2O	(2) N	K_2O	(3) N	K_2O	(4) N	K_2O	Pounds per Acre Totals N	P_2O_5	K_2O
A	40	200	200	60	0	60	0	40	0	200	200	200
B	40	200	100	60	100	60	0	40	0	200	200	200
C	40	200	50	60	50	60	50	40	50	200	200	200
X	40	200	0	60	0	60	0	40	0	200	200	0

* This P_2O_5 may be put on before the N and K_2O.

Arrangement: No. 16, 21 or 24.

Kind of Experiment: TIME TO APPLY PHOSPHATE AND POTASH (TPK)

Treatments	Plan of Fertilization (1) N	P_2O_5	K_2O	(2) N	P_2O_5	K_2O	(3) N	P_2O_5	K_2O	(4) N	P_2O_5	K_2O
A	40	200	250	60	0	0	60	0	0	40	0	0
B	40	200	62	60	0	63	60	0	63	40	0	62
C	40	200	0	60	0	150	60	0	0	40	0	100
D	40	100	0	60	0	150	60	100	0	40	0	100
E	40	50	0	60	50	150	60	50	0	40	50	100
X	40	0	0	60	0	125	60	0	0	40	0	125
Y	40	100	0	60	0	0	60	100	0	40	0	0

Treatments	Pounds per Acre Totals N	P_2O_5	K_2O
A	200	200	250
B	200	200	250
C	200	200	250
D	200	200	250
E	200	200	250
X	200	0	250
Y	200	200	0

Arrangement: No. 31.

Kind of Experiment: AMM. PHOS. + AMM. SULPH. VS. SUPERPHOS. + AMM. SULPH. (X)

Plan of Fertilization							Pounds per Acre		
Treat-	(1)			(2)		(3)	Totals		
ments	N	P_2O_5	K_2O	N	P_2O_5	N	N	P_2O_5	K_2O
X—No P_2O_5	50	0	150	60	0	65	175	0	150
A—Ammophos.	50	125	150	60	75	65	175	200	150
B—Superphos.	50	125	150	60	75	65	175	200	150

Arrangement: No. 6, 7, 10, 11 or 15.

Kind of Experiment: NITRATE OF POTASH VS. AMM. SULPH. + MUR. POTASH (X)

Plan of Fertilization								Pounds per Acre		
Treat-	(1)	(2)		(3)		(4)		Totals		
ments	P_2O_5	N	K_2O	N	K_2O	N	K_2O	N	P_2O_5	K_2O
A—Amm. Sulp. & Mur.	150	50	47	80	74	0	47	130	150	168
B—Amm. Sulp. & Mur.	150	50	47	80	74	50	47	180	150	168
C—Nitrate Potash	150	50	47	80	74	50	47	180	150	168
D—Nitrate Soda	150	50	0	80	0	50	0	180	150	0

Arrangement: No. 17, 19 or 23.

Kind of Experiment: METHOD OF APPLICATION (X)

Plan of Fertilization						Pounds per Acre		
	(1)		(2)	(3)	(4)			
Treat-	Amm.		Amm.	Amm.	Amm.	Totals		
ments	Phos.	Muriate	Sul.	Sul.	Sul.	N	P_2O_5	K_2O
A—By hand	300	150	300	300	200	194	144	90
X—By water	300	150	300	300	200	194	144	90

Arrangement: No. 1, 2, 3, 4 or 5.

Kind of Experiment: PLACEMENT OF FERTILIZER (X)

Plan of Fertilization				Pounds per Acre		
	(1)	(2)	(3)			
Treat-	Amm. Sul.	"P-2"	Amm. Sul.	Totals		
ments		Hi-Grade*		N	P_2O_5	K_2O
A—In the cane line	400	416	400	206	80	80
B—In the row middle	400	416	400	206	80	80
X—In the cane line	300	416	300	163	80	80

* Analysis of "P-2"=9.6 per cent N, 19.2 per cent P_2O_5, 19.2 per cent K_2O. (This may be any "Hi-Grade".)

Arrangement: No. 8, 9, 12, 13 or 14.

Kind of Experiment: LIME (L)

Plan of Fertilization								Pounds per Acre		
Treat-	Tons	(1)			(2)		(3)	Totals		
ments	Lime	N	P_2O_5	K_2O	N	K_2O	N	N	P_2O_5	K_2O
X—No Lime	0	40	300	125	60	125	75	175	300	250
A—Lime (1)	2½	40	300	125	60	125	75	175	300	250
B—Lime (1)	5	40	300	125	60	125	75	175	300	250
C—Lime (2)	2½	40	300	125	60	125	75	175	300	250

(1) Harrowed in before furrowing.

(2) Mixed in the furrow before planting.

Arrangement: No. 18 or 22.

Kind of Experiment: AGE OF HARVEST (AH)

Plan of Fertilization Treatments	(1) N	(1) P_2O_5	(1) K_2O	(2) N	(3) N	Pounds per Acre Totals N	Totals P_2O_5	Totals K_2O
A—Harvest at 12 mos.	50	100	150	60	70	180	100	150
B—Harvest at 15 or 16 mos.	50	100	150	60	70	180	100	150
C—Harvest at 18 or 20 mos.	50	100	150	60	70	180	100	150
D—Harvest at 21 or 24 mos.	50	100	150	60	70	180	100	150

Arrangement: No. 26.

Kind of Experiment: CULTIVATION (C)

Plan of Fertilization Treatments	(1) P_2O_5	(2) N	(2) K_2O	(3) N	(4) N	Pounds per Acre Totals N	Totals P_2O_5	Totals K_2O
A—Subsoiled	150	50	100	60	75	185	150	100
X—Not subsoiled	150	50	100	60	75	185	150	100

Arrangement: No. 1, 2, 3, 4 or 5.

Kind of Experiment: VALUE OF N AND K_2O IN MOLASSES (M)

Plan of Fertilization Treatments	(1) Molasses	(2) N	(2) P_2O_5	(2) K_2O	(3) N	(4) N	(5) N	Pounds per Acre Totals N	Totals P_2O_5	Totals K_2O
A	0 tons	50	250	400	0	60	50	160	250	400
B	5	50	250	0	0	60	50	210	250	460
C	0	50	250	0	50	60	50	210	250	0
D	0	50	250	400	50	60	50	210	250	400

Molasses analyses assumed at .5 per cent N and 4.0 per cent K_2O, or 10 pounds N and 80 pounds K_2O per ton: therefore 50 pounds N and 400 pounds K_2O from 5 tons molasses used on treatment "B."

The fifth application of fertilizer (nitrogen) may or may not be needed.

Arrangement: No. 20, 25 or 19.

Kind of Experiment: VALUE OF N AND P_2O_5 IN PRESS CAKE (X)

Plan of Fertilization Treatments	(1) Fresh press cake	(2) N	(2) P_2O_5*	(2) K_2O	(3) N	(3) K_2O	(4) N	(5) N	Pounds per Acre Totals N	Totals P_2O_5	Totals K_2O
A	0 tons	50	346	150	0	150	76	?	126	346	300
B	10	50	0	150	0	150	0	?	176	346	300
C	0	50	0	150	50	150	76	?	176	0	300
D	0	50	346	150	50	150	76	?	176	346	300

Fresh press cake analyses assumed at 73 per cent water, .63 per cent N, 1.73 per cent P_2O_5, or 12.6 pounds N and 34.6 pounds P_2O_5 per ton of fresh cake.

A fifth application of fertilizer (nitrogen only) may be applied similarly to all treatments.

* This P_2O_5 to be applied as superphosphate.

Arrangement: No. 20, 25 or 19.

Approved "Arrangements of Treatments"
for "GRADE A" experiments with fertilizers, cultural practices, etc.

I.- FOR TWO TREATMENTS

a.- Plots in two columns

No. 1. Preferred (1) arrangement

C.C.	1 X	2 A	3 A	4 X	5 X	6 A	7 A	8 X	9 X	10 A	C.C.
C.C.	11 A	12 X	13 X	14 A	15 A	16 X	17 X	18 A	19 A	20 X	C.C.

No. 2 Alternate (1) Arrangement.

C.C.	1 X	2 A	3 X	4 A	5 X	6 A	7 X	8 A	9 X	10 A	C.C.
C.C.	11 A	12 X	13 A	14 X	15 A	16 X	17 A	18 X	19 A	20 X	C.C.

b.- Plots in three columns

No. 3 Preferred (1)

C.C.	1 X	2 A	3 A	4 X	5 X	6 A	7 A	8 X	C.C.
C.C.	9 A	10 X	11 X	12 A	13 A	14 X	C.C.		
C.C.	15 X 15	16 A	17 A	18 X	19 X	20 A	C.C.		

No. 4 Alternate (1)

C.C.	1 X	2 A	3 X	4 A	5 X	6 A	7 X	8 A	C.C.
C.C.	9 A	10 X	11 A	12 X	13 A	14 X	C.C		
C.C.	15 X	16 A	17 X	18 A	19 X	20 A	C.C.		

c.- Strip Experiment. (1)

No. 5

C.C.	C.C.	C.C.	C.C.	C C.
1 X	5 X	9 X	13 X	17 X
2 A	6 A	10 A	14 A	18 A
3 A	7 A	11 A	15 A	19 A
4 X	8 X	12 X	16 X	20 X
C.C.	C.C.	C.C	C.C	C.C.

"Strip" experiments should be duplicated or triplicated in other parts of the field. Each strip may be divided into several unit plots for harvest data.

LEGEND USED:

A-B-C-D-E-F-X-Y- etc. designate respective treatments of plots as numbered.
C.C.- Crop cane
(1) for "STUDENT'S" method of analysis
(2) for Fisher's "ANALYSIS of VARIANCE"
(3) for either "STUDENT'S" or the "ANALYSIS of VARIANCE"
(4) for experiments that do not need a "CONTROL" treatment.

II.— For Three Treatments

a.- Plots in two columns (where border effect between treatments is not expected to be pronounced, or where border rows will be discarded at harvest.)

No. 6

Preferred: (3)

c.c.	1 A	2 X	3 B	4 A	5 X	6 B	7 A	8 X	9 B	10 A	11 X	12 B	13 A	14 X	15 B	c.c.
c.c.	16 B	17 X	18 A	19 B	20 X	21 A	22 B	23 X	24 A	25 B	26 X	27 A	28 B	29 X	30 A	c.c.

No. 7

Alternate: (3)

c.c.	1 A	2 X	3 B	4 A	5 X	6 B	7 A	8 X	9 B	10 A	11 X	12 B	13 A	14 X	15 B	c.c.
c.c.	16 X	17 B	18 A	19 X	20 B	21 A	22 X	23 B	24 A	25 X	26 B	27 A	28 X	29 B	30 A	c.c.

b.- Plots in two columns (where border effect is expected to be pronounced, or where border rows are not to be discarded at harvest.)

No. 8

Preferred: (1)

c.c.	1 A	2 X	3 X	4 B	5 B	6 X	7 X	8 A	9 A	10 X	11 X	12 B	13 B	14 X	15 X	16 A	17 A	18 X	19 X	20 B	c.c.
c.c.	21 B	22 X	23 X	24 A	25 A	26 X	27 X	28 B	29 B	30 X	31 X	32 A	33 A	34 X	35 X	36 B	37 B	38 X	39 X	40 A	c.c.

No. 9

Preferred: (2)

c.c.	1 A	2 X	3 B	4 B	5 X	6 A	7 A	8 X	9 B	10 B	11 X	12 A	13 A	14 X	15 B	c.c.
c.c.	16 B	17 X	18 A	19 A	20 X	21 B	22 B	23 X	24 A	25 A	26 X	27 B	28 B	29 X	30 A	c.c.

c.- Plots in three columns (with no border effect expected, or where border rows will be discarded at harvest.)

No. 10

Preferred: (3)

c.c.	1 A	2 X	3 B	4 A	5 X	6 B	7 A	8 X	9 B	10 A	11 X	12 B	c.c.
c.c.	13 B	14 X	15 A	16 B	17 X	18 A	19 B	20 X	21 A	22 B	23 X	24 A	c.c.
c.c.	25 A	26 X	27 B	28 A	29 X	30 B	c.c.						

No. 11

Alternate: (1)

c.c.	1 A	2 X	3 B	4 A	5 X	6 B	7 A	8 X	9 B	10 A	11 X	c.c.
c.c.	12 X	13 B	14 A	15 X	16 B	17 A	18 X	19 B	20 A	21 X	22 B	c.c.
c.c.	23 A	24 X	25 B	26 A	27 X	28 B	29 A	30 X	31 B	c.c.		

d. - Plots in three columns (with expected border effect or where border rows will not be discarded at harvest.)

No. 12

Preferred: (1)

C.C.	1 A	2 X	3 X	4 B	5 B	6 X	7 X	8 A	9 A	10 X	11 X	12 B	13 B	14 X	C.C.
C.C.	15 B	16 X	17 X	18 A	19 A	20 X	21 X	22 B	23 B	24 X	25 X	26 A	27 A	28 X	C.C.
C.C.	29 A	30 X	31 X	32 B	33 B	34 X	35 X	36 A	37 A	38 X	39 X	40 B	41 B	42 X	C.C.

No. 13

Preferred: (2)

C.C.	1 A	2 X	3 B	4 B	5 X	6 A	7 A	8 X	9 B	10 B	11 X	12 A	C.C.
C.C.	13 B	14 X	15 A	16 A	17 X	18 B	19 B	20 X	21 A	22 A	23 X	24 B	C.C.
C.C.	25 A	26 X	27 B	28 B	29 X	30 A	C.C.						

e. - Plots in four columns (with expected border effect.)

No. 14

Preferred: (1)

C.C.	1 A	2 X	3 X	4 B	5 B	6 X	7 X	8 A	9 A	10 X	C.C.
C.C.	11 X	12 B	13 B	14 X	15 X	16 A	17 A	18 X	19 X	20 B	C.C.
C.C.	21 B	22 X	23 X	24 A	25 A	26 X	27 X	28 B	29 B	30 X	C.C.
C.C.	31 X	32 A	33 A	34 X	35 X	36 B	37 B	38 X	39 X	40 A	C.C.

f. - Plots in four columns (with no border effect expected.)

No. 15

Preferred: (3)

C.C.	1 A	2 X	3 B	4 A	5 X	6 B	7 A	8 X	9 B	C.C.
C.C.	10 B	11 X	12 A	13 B	14 X	15 A	16 B	17 X	18 A	C.C.
C.C.	19 A	20 X	21 B	22 A	23 X	24 B	C.C.			
C.C.	25 B	26 X	27 A	28 B	29 X	30 A	C.C.			

III – For Four Treatments

a.– Plots in two columns (where border effect is not expected to be pronounced.)

No. 16

Preferred: (1)

C.C.	1 X	2 A	3 B	4 X	5 C	6 A	7 X	8 B	9 C	10 X	11 A	12 B	13 X	14 C	15 A	16 X	17 B	18 C	19 X	20 A	21 B	22 X	23 C	C.C.
C.C.	24 B	25 X	26 C	27 A	28 X	29 B	30 C	31 X	32 A	33 B	34 X	35 C	36 A	37 X	38 B	39 C	40 X	41 A	42 B	43 X	44 C	45 A	46 X	C.C.	

(Where border effect is expected)

No. 17

Preferred: (1) (4)

C.C.	1 A	2 B	3 C	4 D	5 D	6 C	7 B	8 A	9 A	10 B	11 C	12 D	13 D	14 C	15 B	16 A	17 A	18 B	19 C	20 D	C.C.
C.C.	21 D	22 C	23 B	24 A	25 A	26 B	27 C	28 D	29 D	30 C	31 B	32 A	33 A	34 B	35 C	36 D	37 D	38 C	39 B	40 A	C.C.

b.– Plots in three columns (where border effect is expected)

No. 18

Preferred: (3)

C.C.	1 X	2 A	3 B	4 C	5 C	6 B	7 A	8 X	9 X	10 A	11 B	12 C	13 C	14 B	15 A	16 X	C.C.
C.C.	17 C	18 B	19 A	20 X	21 X	22 A	23 B	24 C	25 C	26 B	27 A	28 X	29 X	30 A	31 B	32 C	C.C.
C.C.	33 X	34 A	35 B	36 C	37 C	38 B	39 A	40 X	C.C.								

No. 19

Preferred: (2) (4)

C.C.	1 A	2 B	3 C	4 D	5 D	6 C	7 B	8 A	9 A	10 B	11 C	12 D	13 D	14 C	15 B	16 A	C.C.
C.C.	17 D	18 C	19 B	20 A	21 A	22 B	23 C	24 D	25 D	26 C	27 B	28 A	29 A	30 B	31 C	32 D	C.C.
C.C.	33 A	34 B	35 C	36 D	37 D	38 C	39 B	40 A	C.C.								

c.– Plots in three columns (where border effect is not expected.)

No. 20

Preferred: (1)

C.C.	1 A	2 B	3 C	4 D	5 A	6 B	7 C	8 D	9 A	10 B	11 C	12 D	13 A	14 B	15 C	16 D	17 A	C.C.
C.C.	18 D	19 C	20 B	21 A	22 D	23 C	24 B	25 A	26 D	27 C	28 B	29 A	30 D	31 C	32 B	33 A	34 D	C.C.
C.C.	35 A	36 B	37 C	38 D	39 A	40 B	41 C	42 D	43 A	C.C.								

No. 21

Preferred: (1)

C.C.	1 X	2 A	3 B	4 X	5 C	6 A	7 X	8 B	9 C	10 X	11 A	12 B	13 X	14 C	15 A	16 X	C.C.
C.C.	17 B	18 X	19 A	20 C	21 X	22 B	23 A	24 X	25 C	26 B	27 X	28 A	29 C	30 X	31 B	C.C.	
C.C.	32 C	33 X	34 A	35 B	36 X	37 C	38 A	39 X	40 B	41 C	42 X	43 A	44 B	45 X	46 C	C.C.	

d.- Plots in four columns (where border effect is expected)

No. 22

Preferred : (3)

C.C.	1 X	2 A	3 B	4 C	5 C	6 B	7 A	8 X	9 X	10 A	11 B	12 C	C.C.
C.C.	13 C	14 B	15 A	16 X	17 X	18 A	19 B	20 C	21 C	22 B	23 A	24 X	C.C.
C.C.	25 X	26 A	27 B	28 C	29 C	30 B	31 A	32 X	C.C.				
C.C.	33 C	34 B	35 A	36 X	37 X	38 A	39 B	40 C	C.C.				

No. 23

Preferred : (2)

C.C.	1 A	2 B	3 C	4 D	5 D	6 C	7 B	8 A	9 A	10 B	11 C	12 D	C.C.
C.C.	13 D	14 C	15 B	16 A	17 A	18 B	19 C	20 D	21 D	22 C	23 B	24 A	C.C.
C.C.	25 A	26 B	27 C	28 D	29 D	30 C	31 B	32 A	C.C.				
C.C.	33 D	34 C	35 B	36 A	37 A	38 B	39 C	40 D	C.C.				

e.- Plots in four columns (where border effect is not expected)

No. 24

Preferred : (1)

C.C.	1 X	2 A	3 B	4 X	5 C	6 A	7 X	8 B	9 C	10 X	11 A	C.C.	
C.C.	12 B	13 X	14 C	15 A	16 X	17 B	18 C	19 X	20 A	21 B	22 X	23 C	C.C.
C.C.	24 X	25 C	26 A	27 X	28 B	29 C	30 X	31 A	32 B	33 X	34 C	C.C.	
C.C.	35 A	36 X	37 B	38 C	39 X	40 A	41 B	42 X	43 C	44 A	45 X	46 B	C.C.

No. 25

Preferred : (1) (4)

C.C.	1 A	2 B	3 C	4 D	5 A	6 B	7 C	8 D	9 A	10 B	11 C	C.C.
C.C.	12 B	13 A	14 D	15 C	16 B	17 A	18 D	19 C	20 B	21 A	22 D	C.C.
C.C.	23 C	24 D	25 A	26 B	27 C	28 D	29 A	30 B	31 C	32 D	33 A	C.C.
C.C.	34 D	35 C	36 B	37 A	38 D	39 C	40 B	41 A	42 D	43 C	44 B	C.C.

f.- Special arrangement of four treatments

No. 26

(1) Preferred

C.C.	1 A	2 B	3 C	4 D	5 D	6 C	7 B	8 A	C.C.
C.C.	9 A	10 B	11 C	12 D	13 D	14 C	15 B	16 A	C.C.
C.C.	17 A	18 B	19 C	20 D	21 D	22 C	23 B	24 A	C.C.
C.C.	25 D	26 C	27 B	28 A	29 A	30 B	31 C	32 D	C.C.
C.C.	33 D	34 C	35 B	36 A	37 A	38 B	39 C	40 D	C.C.
C.C.	41 D	42 C	43 B	44 A	45 A	46 B	47 C	48 D	C.C.

IV.- For Five Treatments

a.- A control plot as every third plot:

No. 27

Preferred: (1)

C.C.	A	X	B	C	X	D	A	X	B	C	X	D	A	X	B	C	etc.
C.C.	X	A	D	X	C	B	X	A	D	X	C	B	X	A	etc.		
C.C.	A	X	B	C	etc.												
C.C.	etc.																

b.- Two Latin Squares

No. 28

Preferred: (2)

C.C.	1 X	2 A	3 B	4 C	5 D	6 B	7 A	8 X	9 D	10 C	C.C.
C.C.	11 B	12 C	13 D	14 X	15 A	16 D	17 C	18 B	19 A	20 X	C.C.
C.C.	21 D	22 X	23 A	24 B	25 C	26 A	27 X	28 D	29 C	30 B	C.C.
C.C.	31 A	32 B	33 C	34 D	35 X	36 C	37 B	38 A	39 X	40 D	C.C.
C.C.	41 C	42 D	43 X	44 A	45 B	46 X	47 D	48 C	49 B	50 A	C.C.

c.- Balanced Blocks

No. 29

Preferred: (2)

C.C.	X	A	B	C	D	D	C	B	A	X	X	A	B	C	D	etc.
C.C.	D	C	B	A	X	X	A	B	C	D	etc.					
C.C.	X	A	B	C	D	etc.										
C.C.	etc.															

d.- Duplicate plots adjacent (where border effect is expected)

No. 30

Preferred: (1) (4)

C.C.	A	B	B	C	C	D	D	E	E	D	D	C	C	B	B	A	C.C.
C.C.	B	C	C	D	D	E	E	D	D	C	C	B	B	A	A	B	C.C.
C.C.	C	D	D	E	E	D	D	C	C	B	B	etc.					
C.C.	D	E	E	etc.													
C.C.	etc.																

V.– For Six Treatments

a. – Use a control plot as every third plot.

b. – Use two 6 × 6 Latin Squares.

c. – Use Balanced Blocks.

VI.– For Seven (or more) Treatments

a. – Use a control plot as every third plot.

b. – Use Balanced Blocks

c. – Use a single 7 × 7 Latin Square for 7 treatments; on 8 × 8 for 8 treatments; etc.

No. 31

Preferred (2)

C.C.	1 A	2 B	3 C	4 D	5 E	6 X	7 Y	C.C.
C.C.	8 D	9 E	10 X	11 Y	12 A	13 B	14 C	C.C.
C.C.	15 Y	16 A	17 B	18 C	19 D	20 E	21 X	C.C.
C.C.	22 B	23 C	24 D	25 E	26 X	27 Y	28 A	C.C.
C.C.	29 E	30 X	31 Y	32 A	33 B	34 C	35 D	C.C.
C.C.	36 C	37 D	38 E	39 X	40 Y	41 A	42 B	C.C.
C.C.	43 X	44 Y	45 A	46 B	47 C	48 D	49 E	C.C.

A Required Standard for "Grade A" Experiments

The following *minimum* requirements for "Grade A" field experiments are hereby presented:

1. The *object* of a "Grade A" field experiment shall be one that shall have probable application to an adequately large area of land. It must have the possibility of an economic gain or the detection of loss, or contribute reliable data to either an accredited research project or for a probable research study. It shall be concerned with a problem that is adaptable to field testing.

2. The *plan* for a "Grade A" experiment shall be one that is designed to give reliable quantitative information on the question that is asked of the cane crop. It shall be of such a nature that we can hope to measure the expected differences between treatments with confidence that the differences found are due to the treatment applied and not to chance alone. Large single applications of soluble nitrogen and potash fertilizers will be avoided, and all unchecked variables and other complicated issues will be considered undesirable. The plan must be approved by the Departments of Agriculture and Genetics, of the Experiment Station, before it is installed.

3. The introduced variables or *treatments* may be of any number, providing: (a) they allow of direct adjacent plot-to-plot comparisons, (b) that they are each located adjacent to plots having a common basic control or check treatment, or (c) that they are suitably arranged in blocks, when visible variations *within* such blocks are not evident.

4. The *area* chosen for the field experiment shall be truly representative of the larger area to which its results will have application. Convenience will be a secondary consideration. (A good check on the representativeness is afforded when two or more tests in the same field are given a common treatment.)

5. The experiment *design* and *layout* shall be of such a nature as to reduce the experimental error and to allow a valid estimate of this error when interpreting the results.

(a) Plot *size* is a matter of practical convenience, but there shall be a minimum size of 1/20 acre. No plot shall consist of less than six lines of cane and harvest data should be secured from not less than the four center cane lines of each plot.

(b) The number of *replications* depends on the size of the experimental error, the precision required, or the size of the differences which we are expecting to measure. The following minimum* requirements are presented:

For variety tests:	5 pairs or comparisons for harvest
For fertilizer tests:	7 pairs or comparisons for harvest
For other tests:	7 pairs or comparisons for harvest

(It is recommended that 10 replications or more be installed.)

* The design of an experiment depends to a large extent upon the information sought. When a fine issue needs to be settled where the differences in yield between treatments might be expected to be small, a larger number of comparisons are needed than when a grosser issue is under consideration.

(c) The arrangement of plots shall be such that each treatment will have a similar amount of exposure on roads, trails, track lines, ditches, etc.; guard rows of crop cane are recommended where this exposure cannot be made equal.

6. *Plot areas* for new experiments shall be accurately measured and recorded.

7. *Cultural operations* on all plots shall be uniform (except for those differentials that are being tested). Errors which can influence the results will necessitate the discarding of plots so affected and may thereby automatically remove the experiment from its "Grade A" to a "Grade B" or non-accredited status. Such errors may be: (a) failure to maintain a good stand of cane, (b) accidental burns affecting plots unequally, (c) animal damage, (d) cutting seed before harvest data are obtained, etc.

8. *Harvesting operations* shall be carried on in such a way that accurate cane yields from each plot will be secured.

(a) It is recommended, but not required, that the two outside rows in all 6- or 8-line plots be discarded at harvest; where there are 10 or more lines per plot, these outside lines may, however, be included.

(b) With heavy-tonnage cane, where the cane sticks are so tangled at the borders of the plot that the errors of separation are apt to be large, it is recommended that the cane be carefully separated on the border *prior* to cutting the rest of the plot.

(c) Where cane is weighed in the field, either all the bundles on each plot shall be weighed or gross plot weights shall be calculated from an average bundle weight that shall be obtained by weighing not less than 40 regular field bundles, systematically selected on each plot. An average tare for each plot shall be determined from the gross and net (cleaned) weights of at least six average bundles per 1/20 acre plot, taken at random from scattered points. (Each cutter should be represented by the bundles tared.) Plot yields shall be recorded as net clean cane weights.

9. *Cane sampling* for juice analysis should be resorted to only when it is impossible to crush all of the cane harvested separately for each plot.

(a) Wherever possible all cane grown on each plot shall be crushed separately, in order that analyses of individual plot crusher juices be made therefrom.

(b) Where it is impossible to maintain individual plot identities through the crusher, the cane sampling shall be considered reliable only when each treatment is adequately sampled at least three or four times.

(It is extremely desirable that flumed cane samples consist of cleaned cane only.)

10. The *collection* of the *juice sample* shall be of such a nature that every part of the cane sample crushed shall have an equal chance of being represented in the juice sample that goes to the laboratory for chemical analysis.

Departments of Agriculture and Genetics.

Potash Occurring in Irrigation Water in Relation to Plant Fertilization

By Francis E. Hance, Q. H. Yuen, E. K. Hamamura, T. Nishimura and Paul E. Chu.

Foreword

Sixty-five per cent of Hawaii's sugar crop is grown under irrigated conditions. It has been estimated that a half-million gallons of irrigation water are required per ton of sugar produced. Approximately 325,000 million gallons of water are applied to Hawaiian sugar lands for each crop. All irrigation waters carry salts in variable amounts; in most of them sodium chloride (common salt) predominates. Some pump waters carrying in excess of 100 grains of salt per gallon are found entirely satisfactory as an irrigation supply. Potable water seldom contains more than 25 or 30 grains of salt per gallon. As an illustration of the enormous tonnage of salt involved in the irrigation of sugar cane we cite an hypothetical case. Were it possible for the entire Hawaiian irrigated cane area to employ a water containing as little as 12 grains of sodium chloride per gallon, a water superior to the usual municipal supply, then, as much as 270,000 tons of salt would be carried with it to the cane lands during the period required for a single crop to reach maturity.

Mountain streams may carry as little as 8 pounds of potash per million gallons. Rarely have we found in these waters a concentration exceeding 60 pounds K_2O per million gallons. Waters from artesian basins, however, contain considerably greater quantities of salts, including potash. In general the chlorides of sodium, calcium and magnesium dominate. A survey of analyses of irrigation waters made by the Chemistry Department over a period of several years shows potash to vary between 18 and 507 pounds K_2O per million gallons of water. Maui pump waters are generally richer in potash than are those of the other Islands.

A large portion of the water required for cane irrigation is lifted from underground basins. Operating from artesian wells at maximum capacity, pumps of three plantations on Oahu deliver a total of 270 million gallons of water per 24 hours.

Amounts of Potash Applied by Irrigation Waters Per Cane Crop Cycle:

The volume of water used per crop in the irrigation of Hawaiian cane lands and the tonnage of sodium and potassium salts thus carried to these areas run into figures of astounding magnitude. Assuming an irrigation requirement of 3 million gallons of water per long crop, Hawaiian waters pumped from wells carry to an acre of land amounts of potash varying from 53 to 1,521 pounds of K_2O. The concentration of potash is dependent entirely upon the source from which the water originates. It is within the limits of probability to expect that the potash thus furnished may function to some extent in plant nutrition. Field experiments with varying amounts of potash applied as fertilizer upon irrigated plantations not infrequently show negative response. This finding may be traceable to the

use of irrigation waters naturally high in potash. To illustrate: In a potash fertilization test conducted in a field of a plantation situated on Maui, the 1932 harvest results showed no responsive gain from applications of K_2O up to 280 pounds per acre. Upon investigation it developed that the irrigation water used in this field contained 21 parts per million potash as K_2O. Now, assuming an application of 3 million gallons of water per acre for the crop harvested, 525 pounds of K_2O had been supplied to this field by the water alone.

Soil moisture relationships as affected by irrigation have been made the subject of voluminous research. The rôle of irrigation with respect to changes in the physical state of soils as a result of chemical reactions has likewise been studied by workers both here and abroad. Illustrative of this latter phase of the subject is the very important matter of reclamation of soils by methods involving base replacement.

A subject which has received scant attention until recently is that of the possible utilization by the crop of nutrients contained in irrigation waters.

The concentration of potassium salts in Hawaiian irrigation waters appears very small when expressed in terms of normality or in grams of nutrient per unit volume of water. However, the utilization of this nutrient by the crop even in the great dilution in which it occurs, will be suggested later as not only probable but in addition entirely feasible.

The Nutrient Value of Potash in the Irrigation Supply:

A search of the literature reveals very little pertaining directly to the studies described in these pages or to any research of a similar nature. Nevertheless, from his analyses of irrigation waters of the intermountain region of Utah, having a potassium concentration varying from 0.79 to 59 parts per million, Graves (10) calculated that for an irrigation of 2 acre-feet, 4.4 to 266.6 pounds of the element potassium would have been carried to an acre of soil. Graves recognized the economic significance of his findings after having calculated that the highest amount of potassium found would be sufficient to account for 370 bushels of corn, 230 bushels of wheat, or 34 tons of sugar beets.

Growing Sudan grass in pot experiments with potash as the limiting factor, Verret (32) reported obtaining a slight response to this nutrient when supplied from well water of high potash concentration.

Hester (16) in Virginia, found that the flooding of an area with sea water resulted in a measurable increase in replaceable potassium. Page and Williams (28) observed similar effects from ocean inundation upon English soils.

In the attempted rejuvenation of fields which had been under long and continuous cultivation a flood-fallowing system was used in the British Guiana cane areas. An astonishing increase in yields was obtained as a result of the treatment as compared with similar areas not so handled. Commenting on this, Crabtree (5) mentioned that some workers ascribed the beneficial results to the chemical characteristics of waters used. One plant food found in these waters was nitrogen. The amount was reported as 1.5 parts per million. Granting the whole of the nitrogen to have been utilized by the crop, the total amount added for each acre-foot of water employed would have been but 4 pounds per acre. Crabtree reasoned that this

small amount of nutrient could scarcely account for the total crop increases obtained by flooding, but unfortunately he made no observations regarding potash.

From the study of a fallowed area, neither irrigated nor planted to cane nor fertilized with potash salts, as compared with the soil of an adjacent field having been regularly fertilized, irrigated and cropped intermittently for years, one of us (12) found that the two adjoining areas carried similar concentrations of replaceable potash and practically identical amounts of total potash. Since the many successive harvests of cane must have removed from the cropped field considerably more potash than had been applied as fertilizer, this finding gave support to the probability that potash contained in the irrigation water had made up the amount removed by the crop.

Saline Irrigation in Reference to Accumulations of Sodium Chloride in the Five-Foot Soil Profile:

Gow (11) found evidences which indicated that irrigation water carrying a relatively high concentration of sodium salts over comparatively negligible amounts of potassium salts, did not bring about replacement of potassium by sodium in the soil to any appreciable extent. In a study by one of us in cooperation with H. A. Wadsworth, University of Hawaii, soil specimens were collected from a shaft at successive 6-inch intervals downward for a distance of 5 feet. Study of these specimens by Gow (11) showed that the highest concentration of replaceable potash occurred in the upper 6 inches of soil and that the concentration of this nutrient gradually decreased as the lower levels of the excavation were reached. Although about 25 tons of sodium chloride per acre per year had been applied to this area during 20 years of saline irrigation, determination of water soluble and replaceable sodium gave results which indicated that no accumulation of common salt had occurred anywhere within the five-foot profile region.

Replacement Effect of Sodium Salts Upon Soil Calcium and Potassium:

In an earlier soil study by C. F. Eckart (6), lysimeters, fertilized and unfertilized, were irrigated with water containing 200 grains of common salt per gallon of water. The small-scale irrigation was planned in simulation of plantation practice where salt-bearing well water was employed. In addition to the saline treatments other portions of untreated soil were included in the study whereon only fresh water was employed for irrigation. Hartung and one of us (14) in an interpretation of the results of this experiment in the light of knowledge of base exchange, found evidences to support the belief that the sodium introduced had replaced calcium in the soil complex. The replacement effect upon soil potash was also noted.

Irrigation Water as a Nutrient Solution:

Irrigation water having a high concentration of salts may be considered as potentially a nutrient solution. The relation between concentrations of potassium in culture solutions and optimum plant growth has been studied, among others, by Bartholomew and Janssen (2), Parker and Pierre (29) and Johnston and Hoagland

(19). The results obtained by the workers cited indicate that the minimum concentration of potassium requisite for plant growth lies within the range of 2 to 5 parts of potassium per million parts of culture solution. This would be equivalent to irrigation waters carrying respectively 20 pounds and 50 pounds of potash as K_2O per million gallons of water, a concentration *less* than the average for many Hawaiian artesian waters. Artesian waters of Maui contain on an average about 165 pounds K_2O per million gallons, while those of Oahu average about 40 pounds per million gallons. Thus it becomes apparent that any of these irrigation waters could be used as a flowing culture solution without the addition of potash, it being necessary only to supplement it with other nutrients.

In support of this hypothesis we cite the work of H. L. Lyon and H. Brodie (22) who found that H 109 cane could be grown in a culture solution consisting purely of running tap water. This was accomplished when the plant was started from an immature cane stalk of fair length. Thus far cane started from small cuttings or shoots has not developed plants of normal growth in Honolulu tap water. The question, therefore, of the degree of dilution from which cane so started can take nutrition is an open one and offers an interesting subject for future study.

Relationships Between Exchangeable Potash and Crop Response:

Other investigators have shown that plants can utilize potash from the exchange complex. In studying California soils in iron containers wherein barley was cropped continually for 12 years, Martin (24) found that replaceable potassium showed a marked decrease as the result of the cropping. Wilson (34), working with New York State soils, observed similar results in his study of exchangeable calcium and potassium as affected by cropping and fertilization. Relationships between replaceable soil potash and crop production have been reported by other investigators, including Nostitz (27), Breazeale (4), Kelley (20), Hissink (17), Gedroiz (9), Hoagland and Martin (18). Fraps (8), and McCool and Weldon (25) showed that the potassium content of plants was, in general, dependent upon the "available" potassium in the soil. Magistad (23) in field experiments with pineapples, found a marked relationship between the concentration of replaceable potassium in Hawaiian soils and response to potash fertilization.

The Role of Non-Exchangeable Soil Potash in Plant Absorption:

While the relationship of replaceable potash to plant growth is undoubtedly of great importance the role of the non-exchangeable fraction is not without significance. After a practically complete replacement of magnesium and potassium from a Russian soil, Gedroiz (9) found that certain plants were not only able to develop in such an environment but actually produced a more or less normal yield. The plants so grown apparently obtained these elements in amounts sufficient for their needs and hence by inference (provided seed or other introduction did not supply them) were able to utilize the unexchangeable fractions of magnesium and potassium which were originally present in the soil.

The Function of Sodium in Plant Nutrition:

Due to the marked similarity in chemical properties of sodium and potassium, and to the presence of large concentrations of common salt in saline irrigation waters, a brief consideration of the rôle of sodium in plant nutrition may be of interest. Many investigators are of the opinion that sodium cannot replace potassium in plant processes. Hartwell and Pember (15) concluded from their experiments with Rhode Island soils that, while certain functions of potassium in plants may be performed by sodium, potassium is indispensable for other processes, and without sufficient potassium for these requirements, maximum growth cannot be obtained. Krüger (21) in pot experiments with beets in European soils found that, while sodium cannot physiologically replace potassium, its presence permitted plants to use increased quantities of potassium more readily—a very significant point when considered in the light of Hawaiian saline irrigation.

Significant Developments Leading to the Decision to Make the Present Study:

We have stressed the fact that waters from Hawaiian artesian basins contain significant amounts of potash salts. In 1923, Ewa Plantation Company took cognizance of the finding of W. P. Alexander that certain waters from Oahu artesian basins carried sufficient potash, at least theoretically, to supply a major part of the potash requirement of the crop. Utilization of this nutrient from such a source had received little attention up to that time. Noting the fact that cane lands on Maui, cropped for many years, showed no response to potash fertilization, and learning of Mr. Alexander's findings, Dr. A. L. Dean in 1931 proposed that a survey be made of the potash concentration in waters of Alexander & Baldwin, Ltd., plantations. Concurrently W. W. G. Moir, agricultural technologist, American Factors, Ltd., became interested in the subject and made recommendations for research along lines similar to those proposed by Dr. Dean. Accordingly a general potash survey of irrigation waters was made by the Chemistry Department in cooperation with several plantations. These studies seemed to warrant an organized research upon the effect of potash-bearing irrigation waters on soil fertility.

Purpose of the Present Study:

It has been the purpose of the present study: (1) to evaluate the role of potash in irrigation water as it may or may not function in supplying cane requirements in lieu of, or supplementary to, potash fertilization; (2) to determine whether an accumulation of potash may occur in the soil as a result of a great number of successive irrigations with potash-bearing waters; (3) to make a critical comparison of data obtained by determinations of (a) total potash, (b) replaceable potash by neutral normal acetate extraction, (c) one per cent citric acid soluble potash, and (d) potash by rapid field-chemical test.

A logical move, we believed, in such a study was to strike a potash balance for soil, crop, fertilization and irrigation. Such an accounting, if obtainable, may be based upon the potash found in the soil at the moment and that originally existing in the field as shown by analyses of adjacent virgin areas. These figures supplemented by data relative to fertilization and the amounts of the nutrient estimated

to have been removed by successive cropping may be studied in the light of the quantities of potash which may have been added (or removed from) the soil by irrigation waters. Thus a conclusion could be reached, by inference or by calculation, or by both, as to whether the potash carried in irrigation water had or had not functioned as a plant nutrient and, further, whether the potash reserve had been increased or decreased as a result of successive irrigations and croppings.

Plan of the Investigation:

The plan followed in making the study was substantially equivalent to the one just outlined. Soils were selected from a district where crop and fertilization data have been recorded for many years. Determinations of potash were made both in cropped and corresponding virgin areas of the same field. The plan was to learn of any marked deviation in potash concentration of the original soil from that of the cropped area, assuming the corresponding virgin area to approximate the same chemical composition as the field before cultivation.

Field History of Areas Under Consideration:

Through the courtesy of Hawaiian Commercial & Sugar Co., Ltd., and Maui Agricultural Co., Ltd., a total of 100 soil samples from two noncontiguous fields in Central Maui were obtained for us by F. W. Broadbent and O. H. Lyman. Fifty soil samples, representing borings from the surface foot, were collected from each field, twenty-five specimens originating in the cropped area and an equal number in corresponding virgin borders.

Descriptions and records of production and fertilization of these fields are given in Tables I and II.

TABLE I

Crop Production and Potash Fertilization Record.
Hawaiian Commercial & Sugar Co., Ltd.
Field 19B

Crop Year	Variety	Tons Cane Per Acre	Pounds Potash Per Acre Applied as Fertilizer
1911	Lahaina	49.22	73
1912	Lahaina	60.27	88
1913	Lahaina	41.00	70
1914	Lahaina	47.59	66
1915	Lahaina	52.73	24
1916	Lahaina	45.27	28
1917	Lahaina	33.42	0
The field was divided into two parts during the above period, hence a crop is reported for each year. It was fallowed from 1917 to 1923, at which time it was planted.			
1925	H 109	80.27	0
1927	H 109	52.02	0
Again fallowed for two years.			
1931	H 109	61.76	100
1933	H 109	74.99	195
1935	H 109	....	101

TABLE II

Crop Production and Potash Fertilization Record.
Maui Agricultural Co., Ltd.
Field 77

Crop Year	Tons Cane Per Acre	Pounds Potash Per Acre Applied as Fertilizer
1903—(Virgin land)	75	99
1905—First Ratoons	63	99
1907—Second Ratoons	44	99
1910—Plant	64	113
1912—First Ratoons	63	77.5
1914—Second Ratoons	64	87.9
1916—Plant	69	63.6
1918—First Ratoons	43	37.4
1920—Second Ratoons	32	15.8
1922—Plant	50	None
1924—First Ratoons	60	None
1926—Second Ratoons	59	None
1928—Plant	65	None
1930—First Ratoons	87	None
1932—Second Ratoons	78	None
1934—Third Ratoons—uncut	..	..

This field received no pump water prior to 1922. Since that time a large proportion of the water applied during the summer months was supplied by the high-lift pump.

Analytical Procedures:

The air-dried samples were analyzed for total, replaceable and one per cent citric acid soluble potash. This nutrient was also determined by a rapid field-chemical method. Results obtained by the latter test are reported on the basis of air-dried soil. The total replaceable and one per cent citric acid soluble data have been calculated to the moisture-free basis and are so reported. The analytical data are presented in Tables III and IV. The results are tabulated as to cropped areas and corresponding virgin borders. Potash concentrations are expressed as per cent K_2O and as pounds K_2O per acre-foot (pounds/acre-foot) of 2.4 million pounds of soil. Arithmetical averages are presented at the bottom of each column.

Total potash was determined by decomposing the soil with hydrofluoric and sulfuric acids, removing interfering cations and precipitating the potassium as the chloroplatinate.

These figures, of course, include potash in the soluble (available) and insoluble (slowly available) forms, the latter being considered as the nutrient reserve. Proper accounting of the nutrient must take into consideration this total amount, for the net change in concentration of potash in the soil as brought about by fertilization, crop removal, and chemical equilibria changes resulting therefrom, must be reflected in the results obtained by this determination.

Replaceable potash data represent quantities of the nutrient which have been extracted by neutral normal ammonium acetate. These data are given as per cent K_2O in the moisture-free soil rather than as milliequivalents of base per 100 grams of soil.

TABLE IV

TOTAL AND AVAILABLE POTASH IN SOILS OF MAUI AGRICULTURAL CO., LTD., FIELD 77

Lab. No.	Soil No.	Total K_2O		Replaceable K_2O		10 Cent. Acid Soluble K_2O		Acre Basis				Virgin							
		Per Cent.	Lbs. Per Acre 2 Ft.	Per Cent.	Lbs. Per Acre 2 Ft.	Per Cent.	Lbs. Per Acre 2 Ft.	Rainfall	Evaporation	Total Evaporation	Deficit	Total K_2O Per Cent.	Total K_2O Lbs. Per Acre 2 Ft.	Replaceable K_2O Per Cent.	Replaceable K_2O Lbs. Per Acre 2 Ft.	Rainfall	Evaporation	Total Evaporation	Deficit
		0.0035	22,410																
		1.063	24,072	0.0561															
		1.019	24,456	0.0431	498	0.0282													
		0.973	23,952	0.0347	701	0.0253													
		0.888	21,312	0.0273	1,127	0.0197													

One means of estimating potash in its relation to soil fertility is to determine the amount extracted by a one per cent solution of citric acid. This method has been used extensively at the Experiment Station for many years. Specimens of the soils under investigation had previously and frequently been analyzed by this method; hence the decision was reached to include this type of analysis in the present undertaking.

One of several assemblies the Chemistry Department has recommended to plantations for rapid estimation of soil fertility is a commercially produced ensemble, the operation of which consists in the extraction of the soil with sodium acetate in dilute acid solution and the later formation of turbidity by a precipitation of potassium-sodium-cobaltinitrite in an alcoholic medium. The degree of turbidity indicates the quantity of potash extracted from the soil and hence may be used as a measure of so-called "availability."

Potash in Soil Solution in Relation to Exchangeable Potash:

It is generally considered that plants obtain their nutrient supply only from constituents which are present in the soil in the dissolved state. It does not necessarily follow, however, that nutrients must be applied to the soil in soluble forms in order to be utilized by the crop. Recent experiments conducted by the Chemistry Department as reported by one of us (13) have shown that the cane plant can feed upon phosphates applied in water-insoluble forms.

The amount of potash in the soil solution may be said to bear a relation to that present in the replaceable soil complex. Some of the soluble potash applied as fertilizer may be "fixed" to a greater or less extent. The greater portion of the fixed potash may be found associated with the replaceable complex, the rate and extent of fixation depending upon the concentration of potash in the added solution, the exchange capacity of the soil and the relative amounts of other bases, including hydrogen present in the water.

Discussion of Data—Statistical Analyses:

The replaceable potash content of H. C. & S. Co. Field 19B soils was found to be nearly two and one-half times that found in M. A. Co. Field 77. This applies to both cropped and virgin areas.

Soils of H. C. & S. Co. Field 19B contain a higher percentage of citric soluble potash than M. A. Co. Field 77 soils. A comparison of data obtained from the cropped and virgin areas of both fields shows evidences of a falling off in citric acid soluble potash as a result, apparently, of crop removal.

H. C. & S. Co. Field 19B soils were shown by the above test to possess about three and one-fourth times as much "available" potash as the M. A. Co. Field 77 soils. The comparison between cropped and virgin areas of both fields gives slight indication of removal of this form of the nutrient as a result of cropping.

An examination of the data by one of us shows the virgin soils to be more variable in potash concentration than the corresponding cropped area. A summary of the results obtained by a study of these variations, expressed in terms of the probable error of single determinations (PEs), is presented below. For purposes of comparison the absolute variation has been reduced to per cent variation of the mean (PEs %), or the coefficient of variation:

TABLE V

A Summary Showing the Average Potash Concentrations, Probable Errors of Single Determinations and Coefficients of Variation in Soils of H. C. & S. Co., Field 19B, and M. A. Co. Field 77.

Hawaiian Commercial & Sugar Co. Field 19B

Field	Per Cent K_2O Average	PEs	PEs %	PEs % Virgin Area / PEs % Cropped Area
Total Potash:				
Virgin area	0.909	0.139	15.3	
Cropped area	0.896	0.122	13.6	
Relative variation ...				1.12
Replaceable Potash:				
Virgin area	0.1268	0.0161	12.6	
Cropped area	0.1293	0.0135	10.4	
Relative variation ...				1.21
1 Per Cent Citric Acid Soluble Potash:				
Virgin area	0.1198	0.0260	21.7	
Cropped area	0.0977	0.0150	15.3	
Relative variation ...				1.42
Rapid Field-Chemical Test Potash:				
Virgin area	0.049	0.0083	17.0	
Cropped area	0.042	0.0046	11.0	
Relative variation ...				1.55

Maui Agricultural Co. Field 77

Total Potash:				
Virgin area	0.926	0.0825	8.9	
Cropped area	0.890	0.0760	8.6	
Relative variation ...				1.04
Replaceable Potash:				
Virgin area	0.525	0.0103	19.8	
Cropped area	0.528	0.0070	13.2	
Relative variation ...				1.50
1 Per Cent Citric Acid Soluble Potash:				
Virgin area	0.0432	0.0104	24.0	
Cropped area	0.0304	0.0040	13.1	
Relative variation ...				1.84
Rapid Field-Chemical Test Potash:				
Virgin area	0.015	0.0036	23.9	
Cropped area	0.011	0.0019	17.2	
Relative variation ...				1.39

The statistical study of the data reveals wide differences between the average values and those of single determinations, thus indicating high soil variation. The coefficients of variation range from 8.6 to 24.0 per cent. Reference to columns 3 and 4 above will show that although such fluctuations exist, differences between virgin and cropped areas are small in most cases. However, a consistently higher variation exists in the virgin soils.

Interpretation of Data Relevant to Fertility. "The Net Normal Potash Requirement":

The scope of the following discussion will be confined to the interpretation of the results relevant to fertility as influenced by the potash occurring in irrigation water. The term "fertility" refers to the capacity of the soil to furnish nutrients.

Using data already presented we look into the matter of crop removal and fertilization in an effort to gain some knowledge reflecting upon any net change in the total potash content of the soils under study. While the minimum quantity of potash required to produce a normal crop of cane has not been accurately determined, the average amount removed has been estimated from researches of Stewart (30), Stewart and Verret (31) and Ayres (1) as approximating 200 pounds of K_2O per 100 tons of millable cane. Calculating on this basis and summarizing Tables I and II, the net amounts of potash used for crop production in excess of that supplied by fertilizers on the Maui areas are as follows:

	H. C. & S. Co. Field 19B	M. A. Co. Field 77
Crops harvested (long crops of 2 years each)	8	16
Crops standing in field at time of soil sampling	1	1
Tons cane per acre harvested	434	916
Pounds K_2O removed by crop as calculated on basis of 200 pounds per 100 tons of millable cane	868	1832
Amount K_2O estimated in standing crop	100	100
Total K_2O removed by crops	968	1932
K_2O added in fertilizers	470	692
Net amount of K_2O in pounds removed by crops above that supplied in fertilizers*	498	1240

* This item will be referred to in the discussion as the "net normal potash requirement of the crop."

Thus it appears that 498 pounds K_2O for H. C. & S. Co. Field 19B and 1240 pounds for M. A. Co. Field 77 represent the net amounts which must have been supplied either by the soil or the irrigation water to meet the requirements of the crops produced.

A statistical examination of the data relating to total potash in the two fields shows no significant differences between the cropped and virgin areas.

STATISTICAL ANALYSIS OF TOTAL POTASH DATA

	Per Cent Potash (K_2O)	
	H. C. & S. Co. Field 19B	M. A. Co. Field 77
Average for virgin area	0.909 ± 0.0277	0.926 ± 0.0165
Average for cropped area	0.896 ± 0.0244	0.890 ± 0.0153
Difference, virgin minus cropped area	0.013 ± 0.037	0.036 ± 0.022
Difference, in pounds K_2O/acre-foot	312	864
Difference ÷ probable error of difference	.35 P. E.	1.64 P. E.
Reliability of difference	Not significant	Not significant

Generalizations Based Upon Data and Field History:

From a consideration of the above data one may conclude that since the total potash content of the soils has not materially changed, the successive irrigations have produced no residual effect. If this be true then we have indications supporting the hypothesis that the net normal potash requirement must have been furnished by the irrigation water applied to the fields.

The potash concentration of the artesian water supplied H. C. & S. Co. Field 19B varied from 26 to 60 parts per million K_2O, and that furnished M. A. Co. Field 77 varied between 32 and 42 parts per million K_2O. From records at hand we believe it reasonable to assume that the potash content of pump water applied to both fields averaged not less than 25 parts per million or 208 pounds K_2O per million gallons of water.

Generalizing further and using as a basis of calculation a value of 3 million gallons of water per long crop, for the eight crops under consideration, we find that approximately 5000 pounds K_2O have been carried to H. C. & S. Co. Field 19B. It is not improbable that the crops obtained the 498 pounds net normal requirement of potash from the total of 5000 pounds supplied in irrigation. Furthermore, since there has apparently been no building up of potash in the soil, then of the remaining 4502 pounds the amount in excess of that lost by leaching must have been used by the plants in luxury consumption.

A study of the field history of M. A. Co. Field 77 reveals the fact that no pump water had been applied previous to 1922 and that, during subsequent years, artesian water has been used, with rare exceptions, only during the summer months. A slight decrease was found in total potash in the cropped soil as compared with the virgin area. This difference of 0.36 per cent K_2O, representing 1.6 times the probable error, although not absolutely significant mathematically, is, we believe, an indication that incipient depletion may be taking place. Mountain water, which supplies the major portion of the irrigation requirement for this field, contains an average of only 2 parts per million potash, an amount equivalent to 16 pounds K_2O per million gallons. The data reviewed thus far, and those which are to follow, seem to indicate that potash in irrigation water, in order to merit consideration in the fertilizer schedule, must be present in excess of a certain minimum concentration.

Replaceable Potash in the Soil With Respect to the Net Normal Potash Requirement:

Many investigators have found that as a result of the practice of continued cultivation without supplying potash in excess of that removed by crops, the replaceable potash content of the soil will be lowered. Citations to researches on this topic have been presented previously in this paper. In view of the many years of cropping undergone by the Maui fields, and considering again the resulting net normal potash requirement of these soils, it is reasonable to expect that the exchangeable potash in the cropped area will be found to be lower in amount than in the virgin area, providing the nutrient has not been introduced from some other source.

A statistical analysis of the data previously presented shows that the concentrations of potash in the cropped areas have undergone no significant changes as compared with those of the virgin localities. Hence, we find support for the presumption that the potash carried to the soil by the irrigation water may account for this finding. The following summary is self-explanatory:

STATISTICAL ANALYSIS OF REPLACEABLE POTASH DATA

	Per Cent Potash (K_2O)	
	H. C. & S. Co. Field 19B	M. A. Co. Field 77
Average of cropped area	0.1293 ± 0.0027	0.0528 ± 0.0014
Average of virgin area	0.1268 ± 0.0032	0.0525 ± 0.0021
Difference, virgin minus cropped area	0.0025 ± 0.0042	0.0003 ± 0.0025
Difference, in pounds K_2O/acre-foot	60	72
Difference ÷ probable error of difference	0.59 P. E.	0.12 P. E.
Reliability of difference	Not significant	Not significant

Statistical figures appear to offer corroboration of the presumption that the irrigation water may have supplied the net normal requirement for crop production. Fraps (8) in his researches found that the total amount of potash removed by a crop from the soil averaged about 3 to 16 times the water soluble potash lost by the soil as a result of crop removal, and about twice the replaceable potash lost in this way. It is of interest to note that in the present study while the difference in quantity of replaceable potash in cropped over virgin area is of no absolute statistical significance, the averages indicate a trend towards a gain rather than a loss. On the other hand, a study of the data relevant to citric soluble analyses shows large decreases in the cropped areas in potash soluble in this medium. Statistical examination of these figures appears below:

STATISTICAL ANALYSIS OF ONE PER CENT CITRIC ACID SOLUBLE POTASH DATA

	Per Cent Potash (K_2O)	
	H. C. & S. Co. Field 19B	M. A. Co. Field 77
Average of virgin area	0.1198 ± 0.00520	0.0432 ± 0.00211
Average of cropped area	0.0977 ± 0.00301	0.0304 ± 0.00080
Difference, virgin minus cropped area	0.0221 ± 0.00600	0.0128 ± 0.00225
Difference, in pounds K_2O/acre-foot	530	308
Difference ÷ probable error of difference	3.68 P. E.	5.70 P. E.
Reliability of difference	Practically significant	Absolutely significant

One Per Cent Citric Soluble Potash and Its Relation to the Net Normal Potash Requirement:

While a difference of four times the probable error is considered significant, 3.68 times the probable error may, for practical purposes, be placed in the same category. The statistical results point to an absorption of potash soluble in one per cent citric acid by the plants in both fields. If the net normal potash requirement of the crop came wholly from potash extractable by one per cent citric acid, then the amount shown to be needed by the H. C. & S. Co. Field 19B may be con-

sidered as having been supplied by the soil. However, this consideration does not hold true in the case of M. A. Co. Field 77. The net normal requirement for this field was calculated as 1240 pounds of K_2O and that represented by the citric acid soluble portion was only 308 pounds. Obviously then, 1240 minus 308, or 932 pounds, must have come from another source. Since there has been no change in the concentration of replaceable potash in cropped and virgin areas, the 904 pounds of K_2O must have been furnished directly by the water. Plants are known to absorb the most easily soluble forms of potash; it is conceded, we think, that potash in irrigation water is unquestionably in solution. Hence, uptake directly by the plant from this source is reasonably possible, and the evidence just cited points to such an absorption.

Potash Determined by the Rapid Field-Chemical Test and Its Relation to Cropping:

A mathematical examination of the results obtained by the rapid field-chemical test shows significant differences to exist in the cropped and virgin areas in both cases. The results are summarized in the following schedule:

STATISTICAL ANALYSIS OF RAPID FIELD-CHEMICAL TEST POTASH DATA

	Per Cent Potash (K_2O)	
	H. C. & S. Co. Field 19B	M. A. Co. Field 77
Average of virgin area	0.049 ± 0.00167	0.015 ± 0.00072
Average of cropped area	0.042 ± 0.00092	0.011 ± 0.00038
Difference, virgin minus cropped area	0.007 ± 0.0019	0.004 ± 0.0008
Difference, in pounds K_2O/acre-foot	168	96
Difference ÷ probable error of difference	3.7 P. E.	5.0 P. E.
Reliability of difference	Practically significant	Absolutely significant

The deficiency in balance of 168 and 96 pounds of potash in the soils as revealed by the rapid field-chemical analyses is insufficient to account for the net normal requirements of 498 and 1240 pounds of K_2O of the respective fields (H. C. & S. Co. Field 19B and M. A. Co. Field 77). It is evident that uptake of potash from a supply in the soil or from added fertilizer must have occurred. Hence, from full consideration of the treatment the fields received and from the data, indications again point to an absorption of potash from irrigation water.

While the percentages of K_2O obtained by the rapid field-chemical method are considerably lower, in general, than those obtained by the one per cent citric acid method, the data derived by both methods are comparable and appear related. Both methods involve acid extraction. In the present study citric acid soluble results bear an average value of 2.6 times that obtained by the rapid field-chemical test. Using this factor, and recalculating the rapid field-chemical test data comparable with the citric acid results, we find that the deficiency in balances of potash in the soils becomes 437 and 250 pounds of potash respectively instead of 168 and 96 pounds. Once more we learn that while in the case of H. C. & S. Co. Field 19B ample potash may have been removed from the soil to make up the net normal requirement, data of M. A. Co. Field 77 reveal a discrepancy of 1240 minus 250 or 990 pounds of potash which, in this case, must have been furnished by the

irrigation water. This finding is therefore in support of the conclusion that potash in irrigation water can and will contribute to plant fertilization.

Fixation in Soils by Potash Contained in Irrigation Water:

Some of our conclusions based upon the data pertaining to replaceable and citric acid soluble potash obtained in the study of the Maui soils are in accordance with observations of McGeorge (26). In his study of the availability of potash in Hawaiian soils, McGeorge found that, for some soils, the addition of potash fertilizers increased the replaceable potash but not the potash extractable by one per cent citric acid. He concluded from his study that in the case of some soils the potash is fixed in a form insoluble in one per cent citric acid.

It is conceivable that plants, when in need of a relatively large supply of potash, may draw upon easily obtainable reserves in the soil. Potash thus removed from the soil may later be replaced by potash contained in the irrigation water. If this be true, then there is reason to believe that the potash thus replaced is more firmly fixed than that originally removed in cropping, for, as successive extractions by the plant take place, we find the concentration of citric acid soluble potash diminishing. The fixation of potash in the soils studied appears to be associated with the replaceable complex. Considering the large amount of potash carried to these fields by the irrigation water, the lack of an increase in the total supply in the soil gives indication that very little is fixed in the non-replaceable or difficultly available state. Volk (33) found that alternate wetting and drying of a soil contributed to the fixation of potash in the non-replaceable fraction, the extent of fixation depending upon the nature and quantity of the soil colloids. However, in his examination of three specimens of Hawaiian soils he found no fixation in two and only to a slight degree in the third.

The fixation of potash in the replaceable complex in the Maui soils, only to the extent of the maintenance of the original level, may be accounted for by the reduction of the base-exchange capacity resulting from the diminution of organic matter in the soil through continuous cultivation. A comparison of the analytical results obtained from the 100 samples shows replaceable potash to be present in amounts about 3.5 times greater than those determined by the rapid field-chemical method.

Availability of Soil Potash as Affected by Cropping and Addition of Potash by Irrigation Water:

The question of availability of the potash determined by various methods, while not directly involved in the present investigation, does, however, warrant some attention. A discussion of the topic as affecting the M. A. Co. Field 77 will illustrate the point. Potash fertilization was discontinued from 1922 until quite recently, an interval of approximately 12 years. The major portion of the irrigation water supplied originated in mountain sources and contained a very low concentration of potash. The analytical results obtained in the present soils study show potash to be present to the extent of:

	Per Cent Potash (K_2O) Cropped	Virgin
Total (K_2O) (1933)	0.0890	0.0926
Replaceable K_2O (1933)	0.0528	0.0525
One per cent citric soluble K_2O (1933)	0.0304	0.0432
One per cent citric soluble K_2O (1927)	0.0550	.....

The figures in the summary show no significant change for total potash, although a trend towards a decrease is in evidence. There is likewise no reduction of replaceable potash, but a measurable loss of citric soluble potash was found in the cropped areas as compared with the virgin soils.

Between the years 1928 and 1933 two field tests in potash fertilization were conducted upon cane areas in the same locality. At the beginning and at the conclusion of these tests, soil analyses were made using the one per cent citric acid extraction method. Potash found in the 1927 citric soluble analysis (7) averaged 0.055 per cent K_2O, whereas the 1933 figure showed a concentration of .03 per cent, a reduction of almost 50 per cent in the 6-year period. The 1930 harvesting results showed no response to applications up to 300 pounds K_2O per acre. The 1932 results indicated no significant gains, but a tendency to respond was reported with an application of 120 pounds.

With respect to H. C. & S. Co. Field 19B, a drain corresponding to that found in M. A. Co. Field 77 is not evident. The following ratios are presented:

SUMMARY OF RATIOS OBTAINED BY CALCULATING FROM THE POTASH AVERAGES OF THE AREAS

	Citric Acid Soluble Replaceable	Rapid Fld.-Chem. Test Citric Acid Soluble	Replaceable Total
H. C. & S. Co. Field 19B:			
Cropped area	.76	.43	.14
Virgin area	.95	.40	.14
M. A. Co. Field 77:			
Cropped area	.575	.362	.059
Virgin area	.825	.346	.057

It will be seen that while the citric acid soluble potash in H. C. & S. Co. Field 19B cropped soil is lowered in concentration, it is still 76 per cent of the replaceable potash, whereas in the cropped soil of M. A. Co. Field 77 the concentration has been reduced to 57.5 per cent of the replaceable potash of that area.

Investigators have shown that plants will absorb potash in large quantities up to a maximum regardless of the needs of the plant for this nutrient. The results obtained by Bartholomew and Janssen (2, 3) indicate that plants have a large capacity for absorption of potassium and that the absorption will be maintained throughout the life of the plants if sufficient available potassium is present in the feeding area of the roots. The uptake of potash by plants is influenced not only by the amount available, but by the presence of other nutrients. Phosphate has been found to influence the uptake of potassium. Sodium has been reported as exercising a similar effect, as noted previously. H. C. & S. Co. Field 19B soils contain a high concentration of readily soluble potash and with the use of irriga-

tion water carrying a high salt (sodium chloride) content, a condition may be suggested as existing in the field which makes for maximum uptake of potash by the cane. The data at hand appear to indicate that additional applications of potash as fertilizer to this field are not necessary. Such additions in the past appear to have resulted in little residual building up in the soil. On the contrary, any application in excess of the minimum requirement of the crop may contribute to luxury consumption.

Factors Influencing the Use of Irrigation Water as a Source of Potash:

If the employment of pump irrigation water is to merit a place in the fertilizer schedule, the following factors, we believe, will have to be considered:

1. Potash concentration of water and total volume used.

2. The concentration of readily soluble potash in the soil as determined by neutral normal ammonium acetate extractions or by the one per cent citric acid method.

From studies so far conducted it is problematical whether mountain water low in potash has any fertilizer value. To decide this issue, a research patterned along lines of the one now concluded might be made to advantage on the fields using mountain water irrigation exclusively.

The artesian water studied in this investigation carried comparatively high concentrations of potash. One of the Maui fields received only a fraction of its water from artesian sources. Since this field gave indications corresponding to those obtained from the area receiving pump water entirely it is safe to assume, we believe, that 10 parts per million, or 80 pounds K_2O per million gallons, is a low limit of concentration below which irrigation water may not merit consideration as a source of potash. However, a modification of this minimum will be permissible if the amount of available potash present in the soil is given consideration.

A marked relationship is noted by some investigators between the amount of replaceable potash in the soil and response by plants to potash fertilization. Magistad (23) found no response to potash added to pineapples grown in field experiments on Hawaiian soils when the quantity of replaceable potash present in the soil exceeds 0.4 to 0.5 milliequivalent per 100 grams of dry soil, or approximately 500 pounds K_2O per acre-foot. Similar correlation for sugar cane grown in Hawaiian soils has as yet not been determined.

Where the supply of available potash existing in the soil is sufficiently high to meet contingencies of increased plant demand, then potash present in the irrigation water, though of a lower concentration than the suggested minimum of 10 parts per million, can still be considered as an available source of this nutrient. Utilization of potash contained in irrigation water may be likened to split applications of fertilizers. According to reports of previous workers a large demand is made upon the soil potash during the boom stage of growth of the cane plant. Sufficient available potash should then be present in the soil to compensate for the smaller applications from water of low potash concentration. For areas receiving water of high potash concentration, say in the neighborhood of 20 parts per million (equal to 160 pounds of K_2O per million gallons), it appears that reserves of im-

mediately available potash in the soil may not be needed. In either case, however, sufficient volume of water should be employed to insure the application of ample amounts of the nutrient.

Conclusions

Successive applications of irrigation water high in potash have apparently created no significant residual effect with respect to this nutrient in the soils studied.

The crops harvested removed more potash than was supplied through artificial fertilization.

The quantity of potash removed by the crops in excess of that supplied by the soil and artificial fertilization is believed to have been furnished by the pump irrigation water used.

Large amounts of naturally occurring potash applied in the irrigation water to soils already rich in the nutrient appear to contribute to luxury consumption.

Potash in irrigation water merits consideration in the fertilizer schedule provided the concentration exceeds 80 pounds per million gallons and the quantity of water used insures a total application sufficient or perhaps somewhat in excess of the requirement of the crop. For soils of low available potash concentration a total application per crop of about 250 pounds of potash from irrigation water apparently may insure soil fertility with respect to this nutrient.

Hawaiian artesian waters contain potash sufficient to meet the normal requirements of a culture solution regarding this nutrient.

Virgin cane areas appear to be more variable in potash composition than soils in cropped fields.

The rapid field-chemical tests for soil potash yields results which are comparable with those obtained by the one per cent citric acid soluble method.

Data from the two fields studied show that replaceable potash determinations bear an average relationship of 1.3 times the one per cent citric acid soluble results and 3.5 times the rapid field-chemical test results.

Summary

Water used for irrigation on Hawaiian cane lands contains potash in variable amounts, the concentration depending upon the source of the water. A study to determine whether such naturally occurring potash contributes to sugar cane fertilization has been completed upon soils from two districts.

The solution of the problem was attempted by striking a balance between the quantity of potash existing in the soil before and after cropping, the amount added as fertilizer and the total removed by a number of crops. A discrepancy in potash balance, if found, might then be shown to have been made up by the irrigation water.

Two fields in central Maui were selected for the study. These fields have received applications of artesian water for a number of years. Crop and fertilization records were supplied through the courtesy of the plantations.

A total of 100 soil samples were analyzed for potash by the replaceable, one per cent citric acid, rapid field-chemical, and total potash methods. In addition to evaluating the data in the light of the problem, a comparative study was made

of the analytical results obtained by the various methods employed.

Potash removed by the crops of both fields was in excess of that supplied by fertilizers and that lost by the soil. As a result of the study, indications are found which support the premise that the potash occurring in irrigation water functions in plant nutrition.

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Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
MARCH 16, 1934, TO JUNE 15, 1934.

Date	Per Pound	Per Ton	Remarks
March 16, 1934	3.09¢	$61.80	Puerto Ricos, 3.08, 3.10; Philippines, 3.10.
" 17	3.06	61.20	Philippines.
" 19	3.06	61.20	Puerto Ricos, 3.05; Philippines, 3.07.
" 20	3.02	60.40	St. Croix.
" 21	2.9733	59.47	Philippines, 2.95, 2.97, 3.00.
" 22	2.95	59.00	Philippines.
" 23	2.97	59.40	Philippines.
" 24	2.95	59.00	Puerto Ricos.
April 5	2.90	58.00	Philippines.
" 6	2.8625	57.25	Puerto Ricos, 2.83, 2.85, 2.90; Philippines, 2.85, 2.87, 2.90.
" 7	2.83	56.60	Philippines.
" 9	2.79	55.80	Philippines, 2.78, 2.80.
" 10	2.72	54.40	Philippines.
" 13	2.725	54.50	Philippines, 2.70, 2.75.
" 16	2.70	54.00	Philippines.
" 17	2.725	54.50	Puerto Ricos, 2.72, 2.73.
" 19	2.71	54.20	Philippines, 2.70; Puerto Ricos, 2.72.
" 20	2.70	54.00	Philippines.
" 21	2.735	54.70	Puerto Ricos, 2.72; Philippines, 2.75.
" 24	2.74	54.80	Philippines, 2.73, 2.75.
" 26	2.80	56.00	Puerto Ricos.
May 1	2.75	55.00	Philippines.
" 4	2.78	55.60	Philippines.
" 5	2.80	56.00	Philippines.
" 8	2.82	56.40	Philippines.
" 9	2.85	57.00	Puerto Ricos.
" 11	2.83	56.60	Philippines.
" 15	2.80	56.00	Philippines, St. Croix.
" 18	2.775	55.50	Philippines, 2.75; Puerto Ricos, 2.80.
" 19	2.75	55.00	Philippines.
June 1	2.74	54.80	Philippines, 2.73; Puerto Ricos, 2.75.
" 2	2.73	54.60	Philippines.
" 4	2.74	54.80	Puerto Ricos, 2.73, 2.75.
" 5	2.755	55.10	Philippines, 2.73; Puerto Ricos, 2.78.
" 6	2.78	55.60	Puerto Ricos, Philippines.
" 7	2.765	55.30	Philippines, 2.73; Puerto Ricos, 2.80.
" 8	2.80	56.00	Puerto Ricos.
" 14	2.91	58.20	Philippines, 2.80; Puerto Ricos, 2.90; 3.03.
" 15	3.05	61.00	Puerto Ricos.